NASA CR-66119

A Study Of Man's Physical Capabilities On The Moon

VOLUME III

WORK PHYSIOLOGY RESEARCH PROGRAM

By W. Kuehnegger, H.P. Roth,
and F.C. Thiede

Prepared under Contract No. NAS 1-4449 by
NORTHROP SPACE LABORATORIES
3401 West Broadway
Hawthorne, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA CR–66119

A Study Of Man's Physical Capabilities On The Moon

VOLUME III

WORK PHYSIOLOGY RESEARCH PROGRAM

By W. Kuehnegger, H.P. Roth,
and F.C. Thiede

Prepared under Contract No. NAS 1–4449 by
NORTHROP SPACE LABORATORIES
3401 West Broadway
Hawthorne, California

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A STUDY OF MAN'S PHYSICAL CAPABILITIES

ON THE MOON

ABSTRACT

A study was made to compare man's energy expenditure and gait characteristics, during self locomotion at various rates, in earth and in simulated lunar gravity conditions. The tests were made for the subject walking and running on the level and on grades up to 30° while in shirt sleeves and while wearing a suit pressurized to 3.5 psig. The results, presented in four volumes, may be useful for the design of space suits and life support systems and the planning of lunar exploration missions and their logistics.

FOREWORD

This volume covers the research in work physiology conducted in "A Study of Man's Physical Capabilities on the Moon", under NASA Contract NAS 1-4449. This contract was administered by Langley Research Center, with Mr. William Letko serving as NASA Technical Monitor.

The study was performed by Northrop Space Laboratories in associated with Case Institute of Technology, Cleveland, Ohio. Dr. Walter Kuehnegger served as the Principal Investigator for NSL. Professor James B. Reswick, Director of the Case Institute Engineering Design Center, guided and directed the work conducted at Case under subcontract.

In view of the complexity and scope of the work performed under this contract, the final report has been organized in four separate volumes (numbered I thru IV). Since the work itself was broken down into phases it was possible to treat each phase individually and document them correspondingly. The four volumes which comprise this report are identified as follows.

CR-66115 Volume I, Part 1 - Lunar Gravity Simulation Facility

CR-66116 Volume I, Part 2 - Instrumentation

CR-66117 Volume II, Part 1 - Biomechanics Research Program

CR-66118 Volume II, Part 2 - Biomechanics Research Program Appendices

CR-66119 Volume III - Work Physiology Research Program

CR-66120 Volume IV - Investigation of Lunar Gravity Simulation Techniques

Volumes I thru III were produced by NSL and have been assigned Northrop Space Laboratories' document number NSL 65-153. Volume IV was prepared from material contributed by Case Institute and reports on their portion of the contract effort. The total report (all four volumes) summarizes the performance during the contract period from 2 November 1964 to 30 September 1966.

The authors of this report (Volume III) wish to express their appreciation to Messrs. F.R. Rizzo, J.L. Schuessler and T.P. Martin for their concentration and effort in the performance of testing and other helpful contributions. Further appreciation is expressed to Messrs. G.D. Fitzgerald and B.P. Lauffer for their endurance as test subjects as well as to Mr. K. L. Forsen for the establishment of the computer program.

CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

	Title	Page

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

A STUDY OF MAN'S PHYSICAL CAPABILITIES ON THE MOON

VOLUME III - WORK PHYSIOLOGY

By W. Kuehnegger, H. P. Roth,
and F. C. Thiede

Northrop Space Laboratories

SUMMARY

This portion of the study was performed to investigate certain work physiological parameters parallel to those of biomechanics on a set of predetermined modes and series of experiments under simulated lunar gravity. The physiological studies under this program therefore had the following principal objectives:

(1) To monitor and record physiological data on respiratory rate and volume, metabolic rate, cardiovascular function and body temperature.

(2) To provide information on the relative bioenergetic stress levels associated with locomotion and performance of tasks under simulated lunar gravity.

(3) To provide physiological criteria relative to performance and tolerance limits, as an aid to operational task planning.

(4) To provide information useful in establishing design criteria for life support systems.

(5) Indirectly, to aid in determining the kinds and degrees of physical activity which may contribute to maintaining physical fitness.

The test results and recordings show that these objectives were achieved by this study. The work physiological and biomechanics results show that man is capable of self locomotion and physical work under simulated lunar gravity conditions. When compared to equivalent earth gravity experiments, it was found that his capability, in general, is greatly enhanced by the reduction in gravity. This was very evident in the self locomotion experiments conducted in pressurized suits.

Valuable data for the logistic support of man, his life support and ECS equipment has been derived. Furthermore, optimum locomotion velocities have been established which are of great importance in the conservation of energy and prevention of fatigue.

The pressure suited experiments have produced data which will be of value in the design of future space suits and in the design of ECS equipment.

The data obtained in this study, although only based on the results produced by one to three test subjects, nevertheless comprises a great step in the determination of man's physical capabilities on the Moon.

The purpose of this pioneering study was to investigate certain tests and to determine first whether they were physically possible or not. Once this possibility was verified, it was investigated further by a complete series of tests. In this way a much wider range of different activities could be explored with a limited number of test subjects. Only when the range of possible activities are established will it become practical to employ a considerable number of test subjects for the establishment of statistical data.

INTRODUCTION

Until man actually lands on the Moon and carries on physical activities under its one-sixth g gravity, information on lunar gravitational effects on his physiological functioning, as well as on his biomechanical performance, will have to be obtained through simulations achievable on Earth.

The method of simulation employed in this program provides a 1/6 g vector through the cg of the subject, normal to a walkway which serves as a simulation of the lunar surface for purposes of experimentation with biomechanical and work physiological performance. Its dominant limitation from the biomechanical standpoint is that body motions are constrained into a single plane.

From an intuitive point of view, it might be expected that the near-horizontal position of the body, providing a one g gravitational force vector acting within the vestibular (position and motion sensing) mechanism of the inner ear in an unaccustomed direction for the "standing" position of the body, could cause problems of orientation through conflict of various sensory inputs. However, it was soon found that after minimal experience and training, and with concentration on the visual clues to positional orientation, the subjects experienced no difficulty. No overt physiological or psychological problems, associated with position, were encountered during the test program.

At the outset, there was no doubt that the simulation technique would produce useful data in biomechanics of body motion. There was less certainty as to the results which might be anticipated in work physiology studies, since the earth gravity vector would be changed in direction, relative to body position in normal activities, though its value would remain the same. This might mean that the work physiological study results would be relevant only in terms of the effects of the simulated lunar gravity on biomechanics. However, as more and more test data developed and was analyzed, and similar maneuvers in earth gravity and under simulated lunar gravity were compared, the initial reservations as to usefulness of the technique were largely dispelled.

Work Activities

The work activities investigated in this study belong to the classification of human self-locomotion, which in turn is defined by particular methods of displacing the human body under its own power. These methods of displacement (self-locomotion) range from crawling to jumping and encompass all body motions involved in the mechanics of progression, whether horizontally or otherwise. Human self-locomotion is produced by a complex interplay between a series of controlled angular segment motions. The following methods of self locomotion were investigated according to Table 2 of this volume:

Walking

Running

Loping

Jumping

Stepping

Climbing a pole

Crawling

The purpose of this discussion is to briefly define these different methods.

Walking: Walking is defined as the gait of a biped in which the feet are lifted alternately with one foot not lifted off the ground before the other touches down. As such, it involves a disturbance of body equilibrium with displacement of the lower extremities that alternately carry the body weight. The body and its segments (limbs) oscillate in walking. Arms and legs tend to swing together with some movement of the head. An activity (walking) cycle for each leg consists of two phases, the stance (weight bearing) phase and the swing phase. There is also a period called "double support" when both feet are on the ground.

Running: This method of self-locomotion is an extension to walking, whereby man proceeds by springing steps. Here the period of "double support" gradually disappears with increasing speed until both feet leave the ground for an instant in each activity cycle. Arms and legs follow the same tendency to swing together but at a correspondingly higher rate.

Loping: This is a variation from the running activity with no period of "double support". The stronger spring steps in loping produce generally a higher translation in height with a simultaneous increase in activity cycle (stride) length. Alternately during the cycle each leg once fully absorbs the impact loads of the body weight. This is followed by the support of the body weight and the propulsion of same. Again the arms will tend to swing in unison with the legs and in fact their inertia may be used to increase the activity cycle (stride) length during loping.

Jumping: As referred to in the experiments conducted, "jumping" is defined as springing freely from the ground while supported by both legs simultaneously.

Man then propels himself like a projectile until he lands on both feet at the end of the cycle. In all of the experiments performed, it was noted that the subject preferred to put one foot slightly forward of the other during the landing and takeoff stance period. This is illustrated in Figure 1.

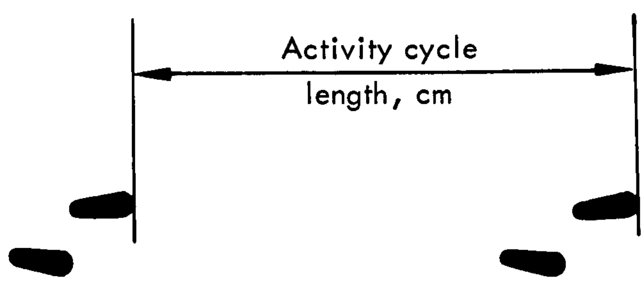


Figure 1. - Foot positions during jumping cycles

Because of this preference, the feet leave the ground almost simultaneously, but land in their positions at different times with the forward leg impacting last. The arms did not swing alternately as during the previous methods of self-locomotion, but swung in parallel. Swinging of both arms forward and up at the highest point of the jump trajectory resulted in increased activity cycle lengths.

Jumping vertically up to and down from a platform is defined by Figure 197 in the test result section of Volume II, Part 1.

Stepping: The stepping experiments for this investigation consisted of stepping stairs in ascending and descending. Thus, it is defined as the alternate raising of the feet and bringing them down elsewhere simultaneously raising or lowering the body, the motion of the arms being similar to walking.

Climbing a Pole: This is defined as an activity during which the human body is raised or lowered with the assistance of a pole. The locomotion method is produced by alternate activities between the arms and the legs. Both hands grasping the pole pull the body upwards while the feet slide loosely along the pole. Upon completion of the arm stroke, the legs and feet grasp the pole supporting the body weight. Extension of the knee joints raises the body farther while the hands slide loosely along the pole. At the end of the leg stroke, the hands grasp the pole, repeating the cyclic activity.

Crawling: This form of locomotion was performed by supporting the body simultaneously with hands, feet and knees at low speeds. At higher rates, the knees were no longer able to touch the ground and the subject moved forward very similarly to a quadruped. During very high rates, the subject supported himself mostly by his toes and fingers rather than his heels and palm of the hand.

METHODS

The method of 1/6 g simulation employed in this program had a major influence on the instrumentation and techniques used to study the physiological effects produced. The geometry and mechanics of this subject suspension system have been described fully in Volume I of this report. The cable suspension from a dolly riding on a rail, with the subject progressing along an inclined walkway, served very well for study of some of the biomechanical aspects of forward locomotion at various rates. However, it did not lend itself as well to the physiological studies, particularly where it was necessary to maintain a certain level of a specific type of activity for a period long enough to obtain valid physiological measurements.

For this purpose, the inclined motor-driven treadmill, described in Part 1, was installed as part of the inclined walkway. This section will therefore be confined primarily to discussion of the physiological methods and instrumentation.

The physiological stresses imposed by various kinds and intensities of physical activity may be evaluated by their effects on a variety of vital body functions. These body functions include respiration, metabolic rate, and cardiovascular function, as well as changes in body temperature, both as an averaged value and as a collection of gradients between various points.

A schematic describing the work physiological parameters monitored and derived from the subject is shown in Figure 2.

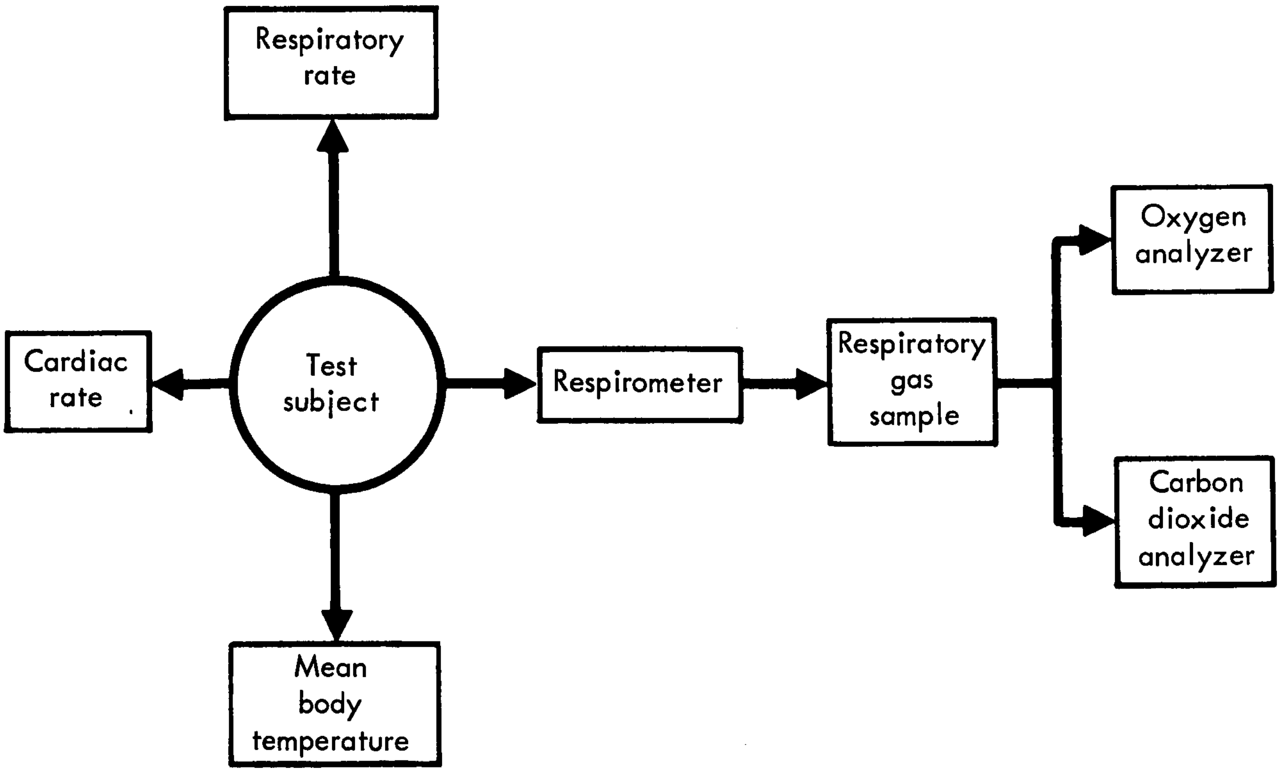


Figure 2.- Work physiological parameters

Respiration

Data on respiration while working in a space suit is needed for two reasons: (1) the severity of physical exertion may be estimated by measuring certain respiratory processes and comparing them with "at rest" baseline values; (2) man's respiratory requirements are basic to adequate suit, helmet and backpack design.

The primary variables measured were respiratory rate (breaths per minute) and minute volume (the product of rate and average volume per breath.)

Respiratory function was evaluated with the aid of a variety of equipment, most of which was also employed in the metabolic rate measurements by the method of indirect calorimetry which depends on measurement of oxygen consumption, carbon dioxide output, or both. Respiratory rate was monitored by use of a sensor in the expiratory air circuit, which actuated a microswitch as each exhalation began. Readout was provided by a respiration tachometer. This tachometer had a meter calibrated in breaths per minute, which indicated the respiratory rate per minute equivalent to the time period per breath. This meter is the upper one of the three seen in Figure 3 and was used, as was the cardiotachometer, to follow the condition of the subject during a test. A permanent record of the respiration was also provided by a galvanometer tracing on the strip chart recorder. Data from this tracing, rather than from the monitoring panel meter, were used in the subsequent physiological analysis.

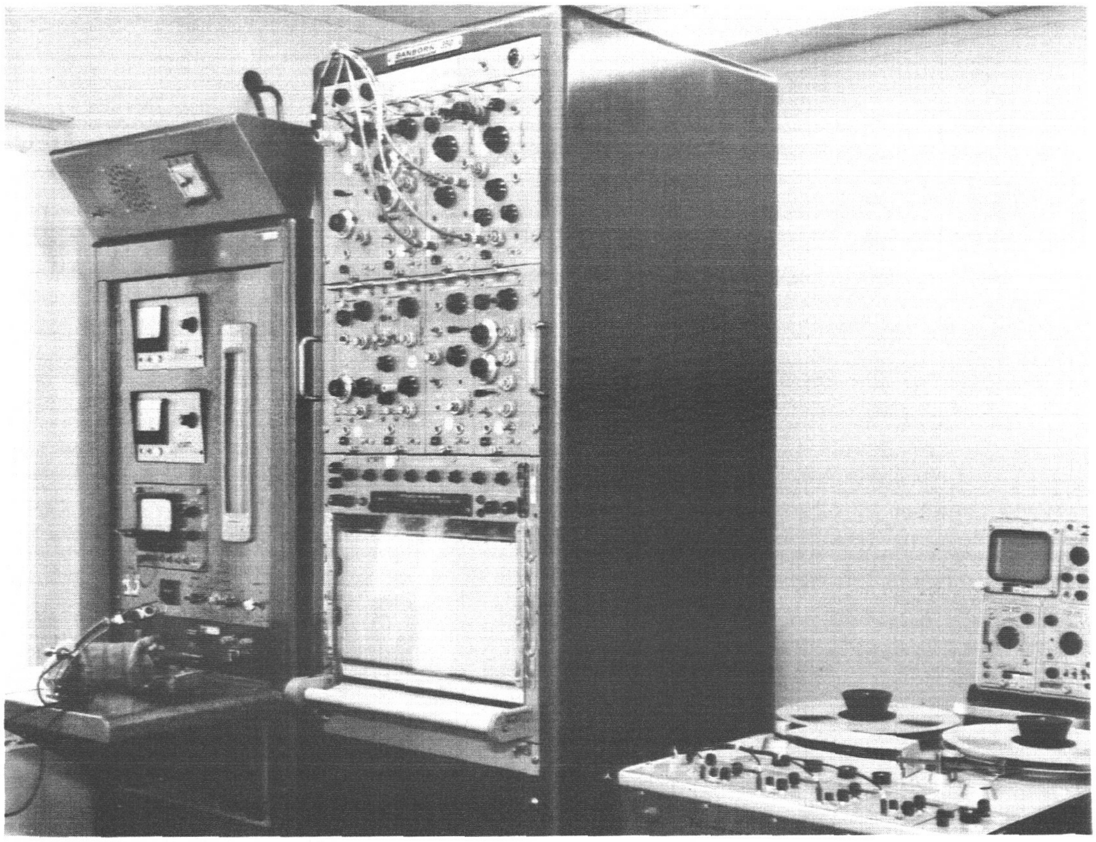


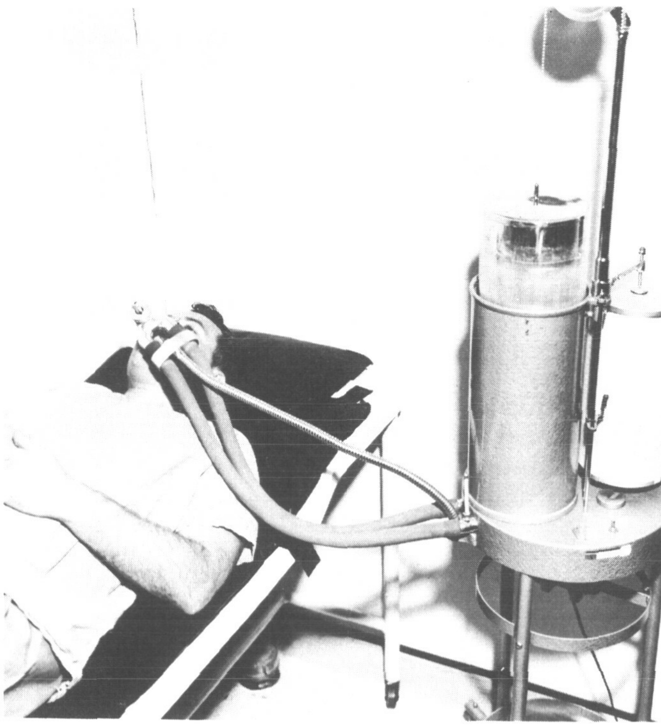
Figure 3. – Instrumentation used for monitoring and recording of work physiological parameters

Metabolism

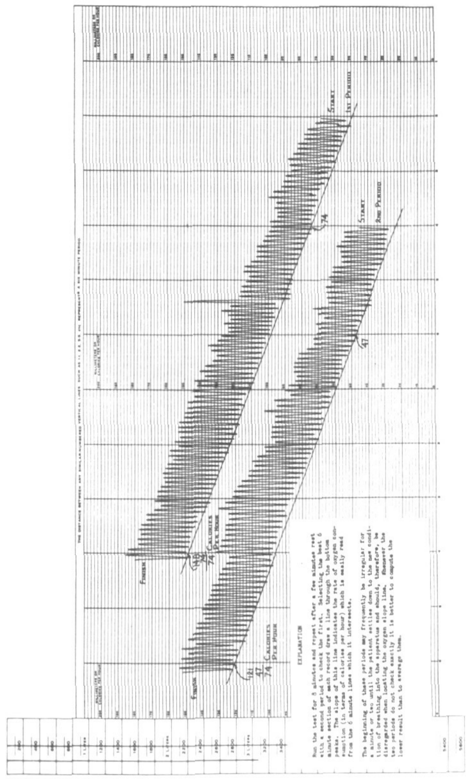
The use of a treadmill versus actual walking for metabolic studies was investigated. In comparing the energy expenditure between treadmill walking and floor walking, H. J. Ralston (ref. 19) had proved that the energy contribution by the treadmill motor at velocities from 2.93 to 5.86 km/h (1.82 to 3.64 mph) were insignificant. A brief visual verification was also made in Vol. II by comparing the biomechanics of locomotion of actual walking with treadmill walking. This comparison indicated no significant differences.

Basal metabolism determination. - The basal metabolism tests of the subjects, during their preliminary evaluation, were performed with a clinical metabolism apparatus, as shown in Figure 4A; a typical record is seen in Figure 4B. For a basal test, the subject reports in the morning in the post-absorptive state (with no food intake for 12 or more hours previously), and rests, lying down, for about 20 minutes prior to the test. The metabolism determination by this apparatus depends on measuring the rate of oxygen consumption by the change in level of a spirometer bell during the course of the test. A closed circuit is used; oxygen is added to the spirometer prior to the test, and the carbon dioxide exhaled is absorbed as the expired gas passes through a CO_2-absorbent chemical bed within the apparatus. The apparatus provides a graphic record of respiration, during which the metabolic use of oxygen by the body causes a continuous change in the level of the spirographic record. The change in this level for a six minute (0.1

hour) period is corrected to standard conditions and expressed as a metabolic rate in kilogram-calories (kcal) per hour. This figure is then compared with statistical averages to determine whether or not it is "normal."



A. - Test arrangement using Benedict-Roth apparatus



B. - Sample BMR record

Figure 4.- Determination of basal metabolic rate

Metabolic rate. - Determination of metabolic rate during work performance provides a quantitative measure of the energy-exhange level involved in work activity. It is customarily expressed as the rate of heat production of the body per unit of time (minute or hour). Metabolic rate may be computed from the rate of oxygen consumption, to which it is directly proportional. The method of "indirect calorimetry" chosen from this program depends on the measurement of the pulmonary ventilation volume (minute volume) and determination of the difference in oxygen concentration between inspired and expired air. The rate of production of carbon dioxide (when it can be determined accurately) is an auxiliary metabolic measure related to the rate of heat production. Problems associated with its use and interpretation will be discussed separately.

Respirometers. - The need for measuring metabolic rates during subject activity on the LGS imposed rather stringent limitations on the equipment which might be used for this purpose. In general, clinical-type or physiological laboratory apparatus was unsuitable because of weight, size, or position limitations. Much work physiology determination is done in the laboratory using the Tissot open-circuit method, which typically requires a large gasometer or gas-holder of 120-liter size or larger, in which all exhaled air can be collected for a given test period (see Figures 5 and 6).

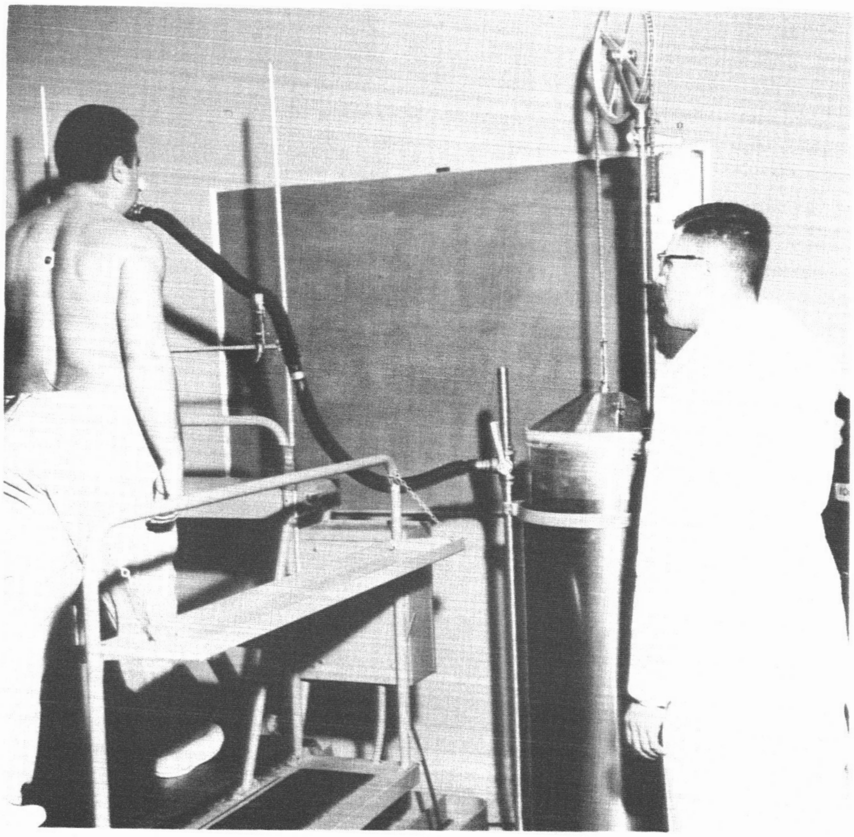


Figure 5. – Metabolic determination of subject on treadmill using Tissot gasometer

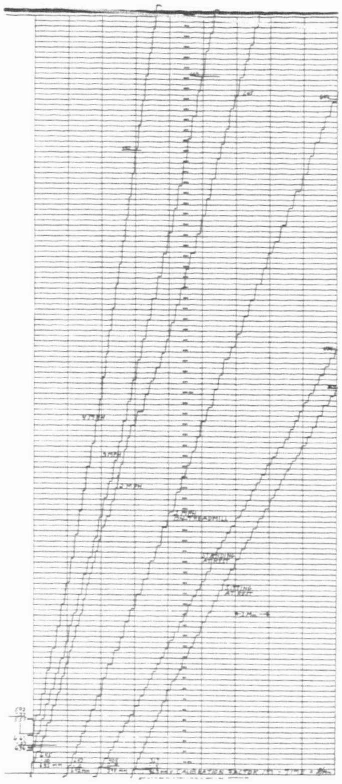


Figure 6. – Sample Tissot gasometer record

The Mueller-Franz meter, chosen for this project, was designed especially for physiological studies of work or exercise, where light weight and compactness are necessary. Figure 7 shows a subject carrying one of these meters, rucksack-fashion, for evaluation of lung ventilation and metabolic rate during a treadmill test. It precludes need for collection of all the expired air, by measuring the volume of exhaled air by a compact meter, and simultaneously extracting a continous, proportional sample or "aliquot" which is collected in a butyl rubber sampling bag. The sample is typically 0.6 percent of the exhaled air; the volume collected in a typical length of test period is sufficient to provide samples for analysis to determine the oxygen and carbon dioxide concentrations.

A window in the meter case permits reading the accumulated volume indication of the recorder, in liters, at desired intervals; in this case, before and after each test period. Figure 8 shows the reading window; the sampling bag is seen at the left, below.

Two Mueller-Franz meters were used in this program. Each was calibrated for accuracy of gas measurement by displacement of gas from a chain-compensated Tissot-type 120-liter gasometer equipped with a kymograph. The correction factor for Instrument No. 1 on ambient air was 1.02, and on oxygen 0.98. For Instrument No. 2 the respective factors were 1.07 and 1.06.

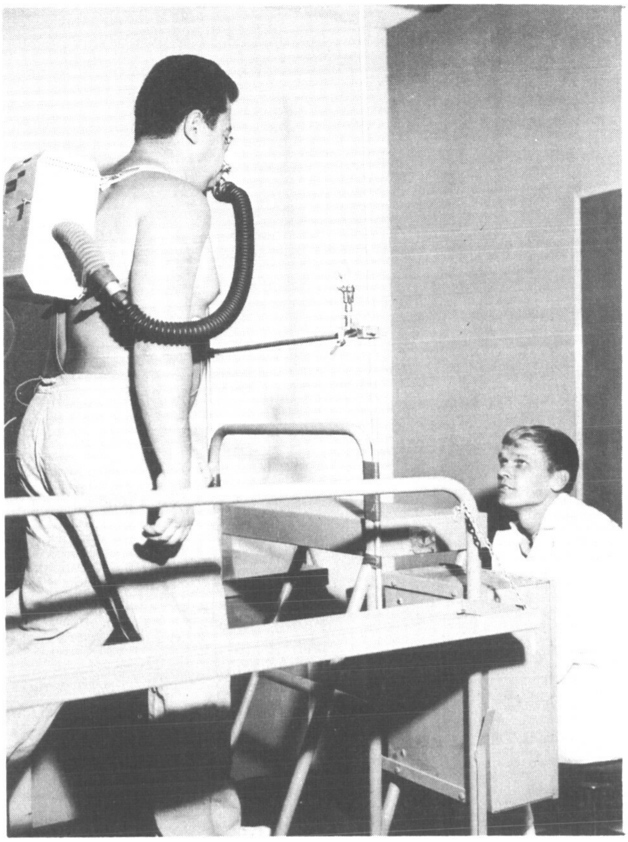


Figure 7.- Metabolic determination of subject on treadmill employing the Mueller-Franz Respirometer

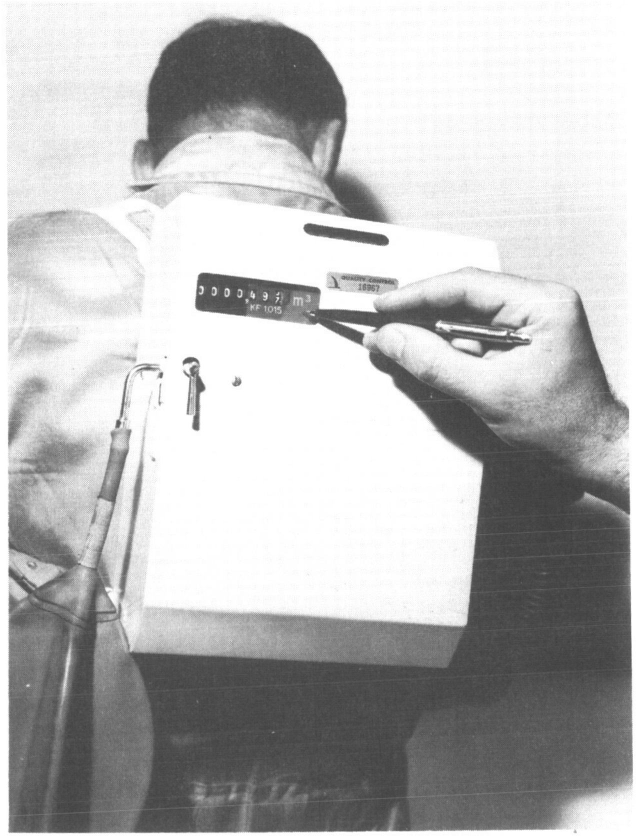


Figure 8.- Typical Mueller-Franz readout in litres with collected expired aliquot

As described in the report section on Instrumentation (Volume I, Part 2), a subject-actuated control was provided which started and stopped operation of the Mueller-Franz meter, including both ventilation volume measurement and collection of the aliquot sample. The signal for starting and stopping meter operation was given by the test director, who timed the period of measurement by a stopwatch and recorded this time period on the test log sheet.

In order to evaluate possible changes in the gas concentrations of collected samples which might occur between the time of collection and time of analysis, a check was made. Sequential tests at half-hour intervals were performed on typical samples with near-maximum CO_2 concentration (about four to five percent) over periods of 24 and 48 hours. The CO_2 concentration was found to decrease at a rate of only about three parts in 100 per hour. In view of the fact that the concentration of this gas plays only an indirect and minor part in the calculation of the metabolic rate, and since the samples with CO_2 concentrations in the higher ranges were held the shortest times (analysis was usually performed within about 15 to 30 minutes at the most, after the end of a test session) it was concluded that the effects of CO_2 diffusion were negligible.

Gas analysis. - The expired air samples collected during each period of work activity were analyzed for oxygen and carbon dioxide using standard electro-physical gas analysis instruments. Each instrument was checked for accuracy daily, before test sample analyses, using gas mixtures of certified analysis and one containing gas mixtures whose composition was similar to that of the test samples. The gas analysis apparatus is shown in Figure 9.

Figure 9.- Set-up of gas analysis equipment

Metabolic rate calculations. - All gas volumes used in the metabolic rate calculations were adjusted to standard temperature and pressure conditions $STPD_1$ (0° C and 760 mm Hg.). Metabolic rate, in terms of heat production, was calculated from the pulmonary minute volume as derived from the Mueller-Franz meter readings, and the changes in O_2 and CO_2 concentration between inspired and expired gas (air or 100% O_2), and the analyses of expired gas samples. The respiratory exchange ratio (RER) previously known as the respiratory quotient, (R.Q.), the ratio of volume of CO_2 exhaled to the volume of O_2 absorbed in the lungs, per unit time period, was calculated for the sample from each separate test period. It was used, when within limits of 0.7 to 1.0, as a factor determining the caloric equivalent of the oxygen used.

Expired air collected either in the sampling bag of the portable Mueller-Franz respirometer or the clinical Tissot Gasometer during an interval of work activity was analyzed for O_2 concentration in a Beckman Model E-2 Oxygen Analyzer and for

CO_2 concentration in a Beckman Model LB-1 Medical Gas Analyzer. Calculations of O_2 consumption, CO_2 production and metabolic rate are made in the following manner:

O_2 Consumption

(1) $*\dot{V}_{O_2} = (\dot{V}_I \cdot F_{I_{O_2}}) - (*\dot{V}_E \cdot F_{E_{O_2}})$

or

(2) $*\dot{V}_{O_2} = *\dot{V}_{I_{O_2}} - *\dot{V}_{E_{O_2}}$

*All volumes adjusted to STPD conditions (0°C + 760 mm. Hg)

(3) $\dot{V}_I = \dot{V}_E \cdot \dfrac{F_{E_{N_2}}}{F_{I_{N_2}}}$

$\dot{V}_{O_2}$ = O_2 consumption (liters/min)

$\dot{V}_I$ = inspired minute volume (liters/min)

$\dot{V}_E$ = expired minute volume (liters/min)

$\dot{V}_{I_{O_2}}$ = inspired O_2 volume (cc/min)

$\dot{V}_{E_{O_2}}$ = expired O_2 volume (cc/min)

$F_{I_{O_2}}$ = fraction of inspired O_2

$F_{E_{O_2}}$ = fraction of expired O_2

$F_{E_{N_2}}$ = fraction of expired N_2

$F_{I_{N_2}}$ = fraction of inspired N_2

CO_2 Production & Respiratory Exchange Ratio

(4) $\dot{V}_{CO_2} = \dot{V}_E(F_{E_{CO_2}} - F_{I_{CO_2}})$

(5) $R = \dfrac{\dot{V}_{CO_2}}{\dot{V}_{O_2}}$

(6) $MR = \dot{V}_{O_2} \cdot O_{2_{CE}} \cdot 60$

$\dot{V}_{CO_2}$ = CO_2 production (cc/min)

$F_{E_{CO_2}}$ = fraction of expired CO_2

$F_{I_{CO_2}}$ = fraction of inspired CO_2

$O_{2_{CE}}$ = caloric equivalent for a liter of O_2 at calculated R (K cal/liter of O_2) Ref. Figure B2, pg. 333

MR = metabolic rate (K cal/hr)

Respirometer check on 100% oxygen breathing. - Figure 10 shows the setup for a test which was conducted as a check on procedure for estimation of metabolism, using the Mueller-Franz respirometer while the subject breathes 100 percent oxygen from the gasometer. The decrease in gasometer volume provided a measure of the inhalational lung ventilation rate ($\dot{V}_I$), while the respirometer reading provided the exhalational lung ventilation rate ($\dot{V}_E$).

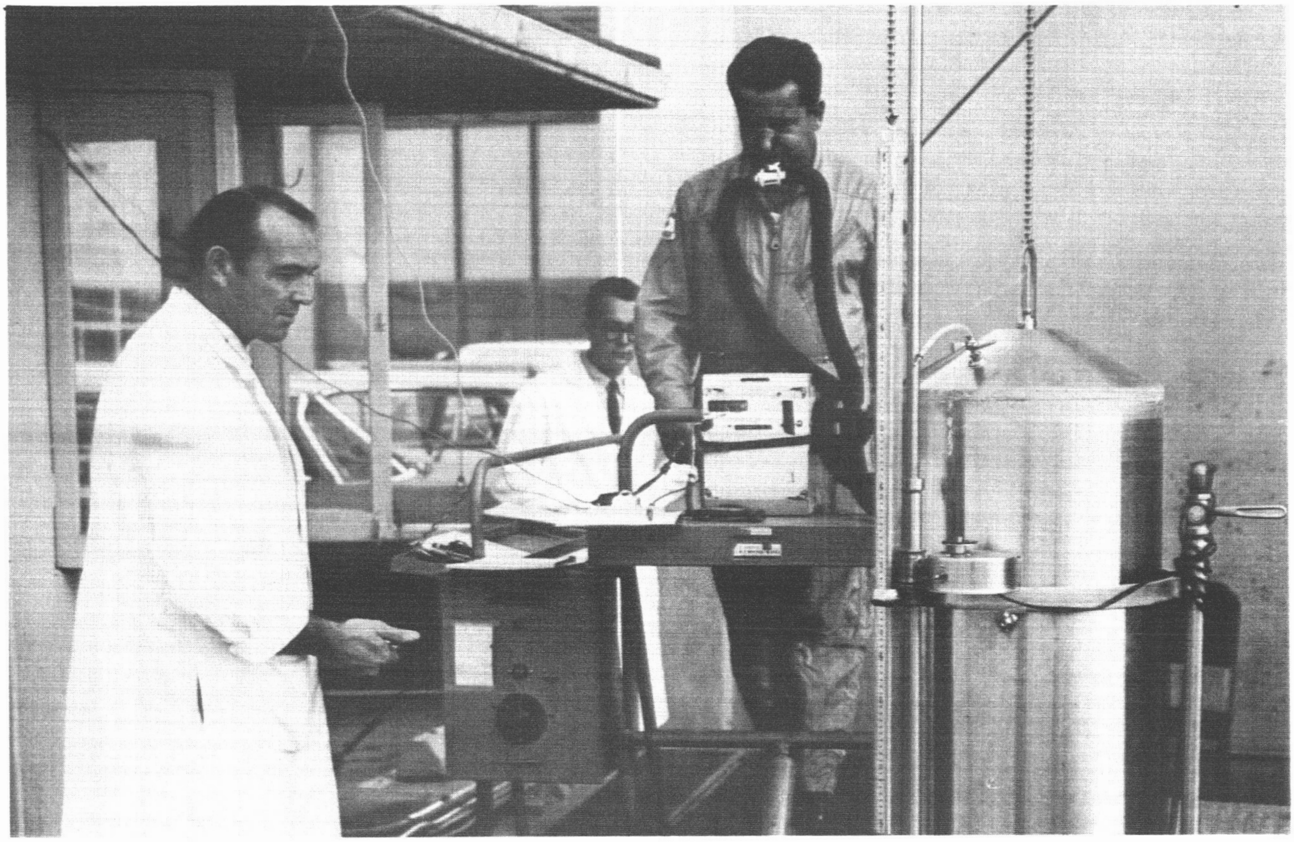


Figure 10. - Test setup for metabolism procedure check-out

Information on both these factors is necessary, in addition to the analysis of exhaled air, to enable calculation of metabolic rate by the open circuit method when the subject breathes 100 percent oxygen as was done when the suit was used in pressurized condition. In this test, as well as in pressurized suit operation, the subject breathed pure oxygen for a preliminary period of at least 10 minutes, to wash out nitrogen from the lungs.

Cardiovascular Function

One of the most important physiological changes produced by muscular activity is the resultant increase in blood circulation to the exercising muscles. Monitoring of cardiovascular function provides useful information regarding the level of work stress.

The heart rate was measured to determine the extent of functional response of the cardiovascular system to work. Furthermore, it is now recognized that changes in heart rate correlate well with work load through a considerable range of experimental conditions. This is particularly true if subjects can be individually "calibrated", and providing thermal stress does not become a significant factor.

Cardiac rate or heart rate was first monitored using a modification of the system suggested by Freiman et al (ref. 6). One positive and one negative electrode were placed bilaterally on the anterio-lateral aspect of the rib cage at the level of the 8th or 9th rib. A ground was placed between the shoulder blades at the 5th or 6th thoracic vertebra as shown in figure 11.

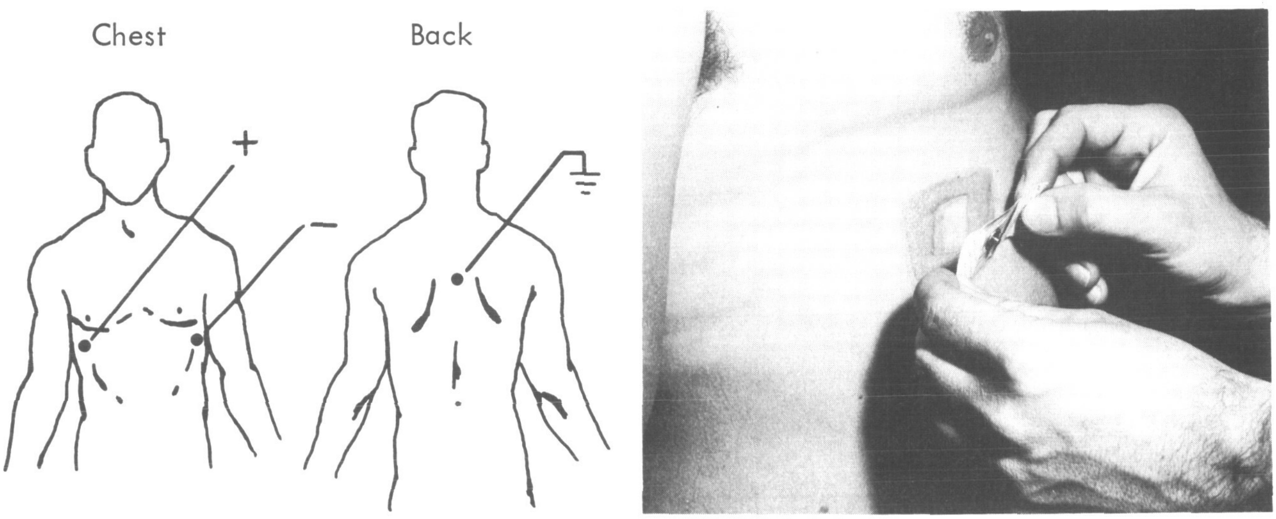


Figure 11. - Bilateral placement of electrodes

Unstable read-out of heart rate record while on the lunar gravity simulator, due to pressure from the body suspension on the sensing electrodes, dictated a change-over to sternal leads. These permitted their placement nearly directly over bone, which cut down muscle artifacts. Further, the attachment over bone insured longer lasting skin-electrode contact. Sternal leads have produced readings with higher voltage amplitudes, because of their proximity and orientation to the heart.

In addition, a protective rubber ring was secured over the electrode to prevent the body suspension hardware from pressing the suit and causing it to rub directly on the electrode. Installation of a new coaxial cable improved the stability of the cardiac rate meter.

With this electrode configuration as shown in Figure 12, cardiac rate was discernible from the Sanborn graphs 85% of the time; however, the signal was still intermittent and the cardiac rate meter was very unstable at times.

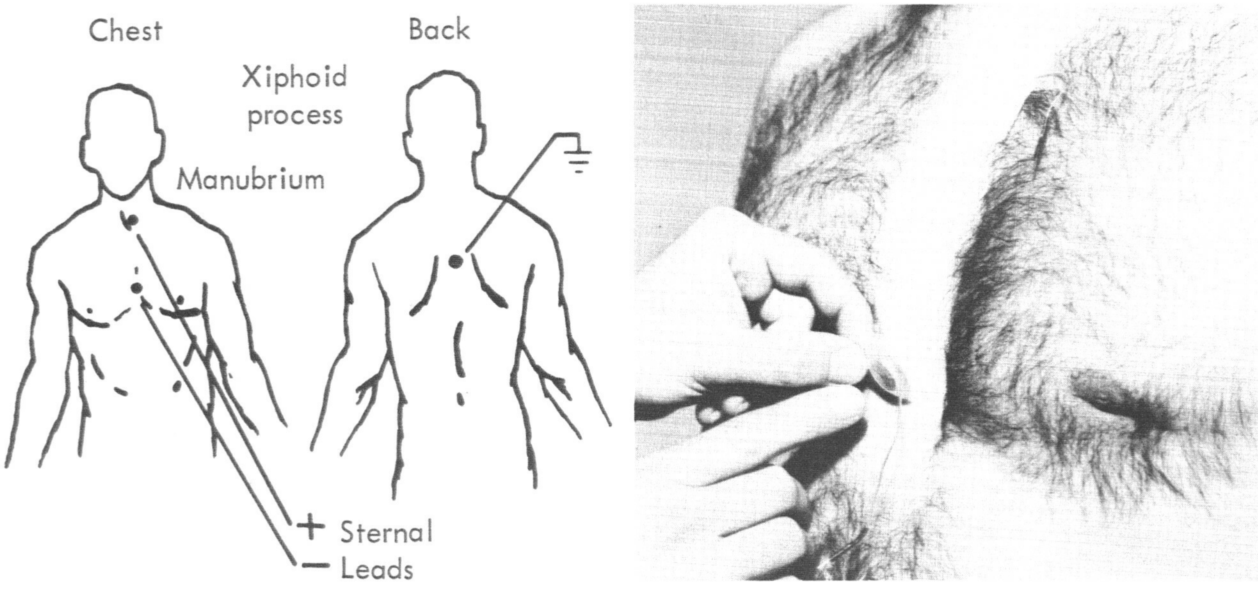


Figure 12. - Placement of ECG electrode

Modified Mercury ECG flight electrodes, procured through NASA Manned Spacecraft Center (MSC), were tried as a means of eliminating noise caused by the former telemedic electrodes. The new Mercury ECG electrodes were first applied to the sternum with a ground on the back of Subject A; this provided poor cardiac rate readouts during task performance on the lunar simulator. The electrodes were then applied in the original bilateral placement resulting in discernible cardiac rate from the biomedical recorder during 95% of the time. The cardiac rate meter's stability improved and deflected only during a vigorous task, but returned to a stable position 2-3 seconds from completion of the vigorous task.

Typical samples of ECG recordings according to the electrode placement in Figure 12 are shown in Figures 13 and 14.

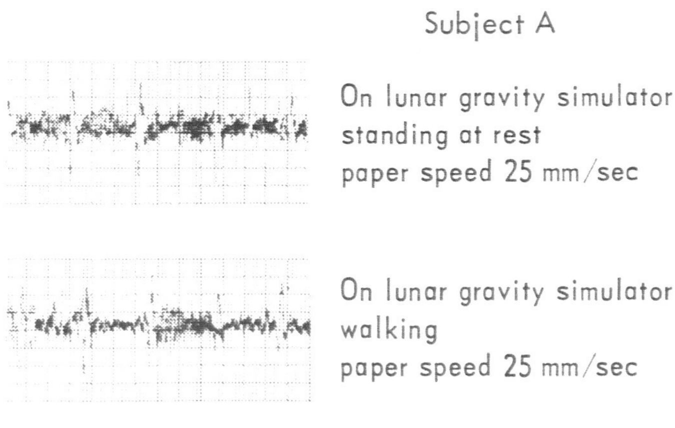


Figure 13.- Sternal electrode placement

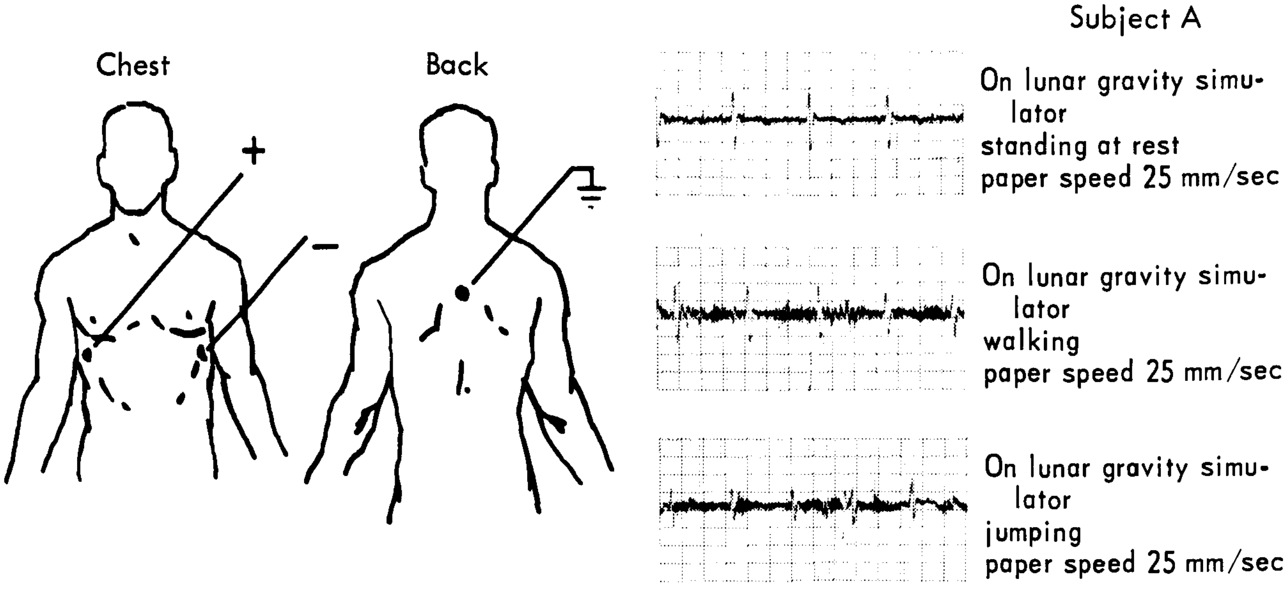


Figure 14.- Bilateral electrode placement

The modified Mercury ECG flight electrodes were later replaced by Beckman electrodes which yielded an excellent signal-to-noise ratio even during vigorous activity. Filtering of muscle potential was accomplished using the band-pass filter of the Sanborn 350-2700 high gain amplifier.

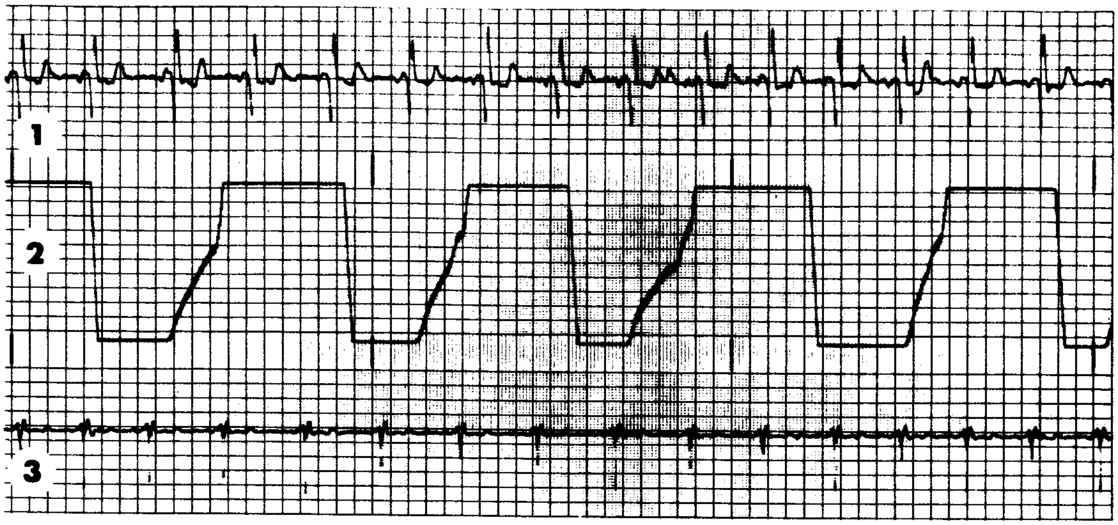
The resulting series of electrical impulses, one for each heart beat, was fed into a cardiotachometer (the middle instrument of the three at the left of the monitoring console shown in Figure 2, Vol. 1, pt. 2) which provided a direct reading of heart rate in beats per minute.

The heart voltage pulses were also fed to a galvanometer unit on the stripchart recorder. This provided a continual graphic record of heart rate during each experimental period, for correlation with other physiological data similarly recorded.

These two means of measuring the heart rate were complementary and therefore valuable in different ways. The meter indication of the cardiotachometer was used primarily to follow the condition of the subject during the test, particularly in response to changing conditions. Sudden changes in the indicated rate were usually associated with artifactual electrical input due to electrode trouble or impulses from non-cardiac sources, and could be easily disregarded.

The beat-by-beat trace of the T-wave on the strip-chart recorder provided the basic heart rate information for the physiological analysis. Here also, irregularities due to electrical artifacts could be detected and only those portions of the record used for heart rate estimation which obviously were valid, "clean" records. Both chart movement at the known rate and the one-second-pip timing trace provided the time base which enabled calculation of the heart rate from the number of beats per unit of time. Most heart rate counts were for a full half-minute.

A typical strip chart record obtained during a test is shown in Figure 15.



①Real time - cardiac rate ②Play back - respiration rate ③Play back - cardiac rate

Figure 15.- Sample strip chart record

Body Temperature

Activity and work generate heat which is additive to the normal rate of heat production of the internal living processes of the body at rest. This heat constitutes roughly 80 per cent of the energy "consumed" in the activity. Adjustments of physiological processes (principally blood circulation) to keep the rate of heat transfer to the environment in balance with the total rate of heat production constitute the principal bodily response to increased activity, from the thermal point of view. If metabolic heat is not dissipated, the body will "store" heat and its temperature will rise. A slight rise in body temperature is practically inescapable in any activity.

Monitoring of body temperature is thus a useful measure of stress associated with activity, though the effect of the body's thermal environment on rate of heat loss must also be considered. It is particularly important for a man in a space suit, since this type of garment interferes with convection, vapor transfer, and radiation. Consequently, either forced ventilation of the interior of the suit or some other thermal transport system is required to help maintain body temperature near equilibrium so that the man may perform his tasks adequately. Experience has indicated that at activity levels well within those probable for astronauts on the lunar surface, undesirable body heat storage does occur with a gas-cooled system, particularly in a low pressure environment (refs. 1-4). Experimental procedures on the lunar gravity simulator therefore provided for monitoring body temperature as a means of estimating body heat storage should it occur. In addition, body temperature rise causes a change in the level of functioning in virtually all body system, heart rate in particular.

Estimation of average body temperature was performed according to the general method proposed by Hardy and DuBois (ref. 7), in which temperature measurements are made in a multiplicity of locations, including both surface and core.

Hardy and DuBois empirically determined these weighting factors which actually represent fractions of the total body surface area which are shown in Figure 16.

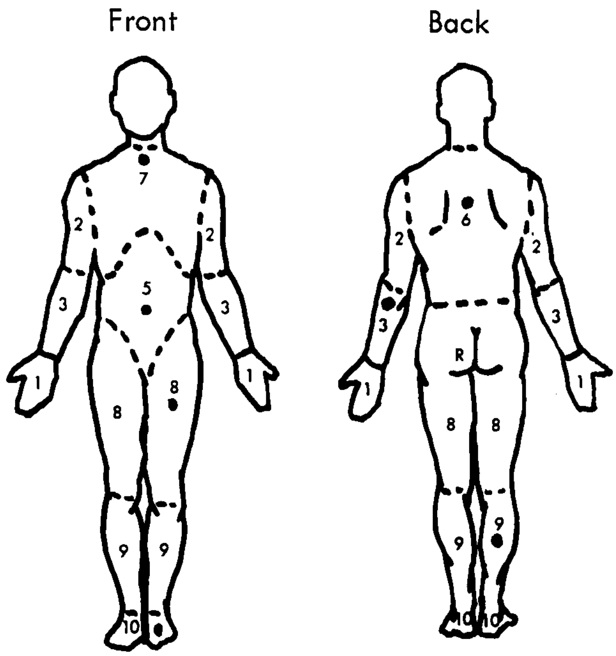


Figure 16.- Location of individual thermistors on the body and divisions of the skin surface for weighting

Ten skin temperature measurements were taken, using surface thermistors, and each was multiplied by a weighting factor (the sum of the weighting factors being 1.0). The mean of these weighted values provides a mean skin temperature, taking all anatomical regions into account, which reflects their relative contributions to a physiologically significant average. The weighting factors and thermistor placement for these anatomical regions are given in Table 1.

TABLE 1 — BODY TEMPERATURE SENSOR DATA

Modified Weighting Factor	Anatomical Region	Thermistor Placement
.07	Head	Mid-forehead
.05	Hand	Back of hand
.06	Forearm	Right upper mid-forearm
.08	Upper arm	Left outer mid-upper arm
.19	Thigh	Right upper mid-thigh
.13	Calf	Left mid-calf
.07	Foot	Dorsum of right foot
.17	Back	Midline of back over 8th thoracic vertebra
.09	Chest	Mid-sternum
.09	Abdomen	Mid-abdomen

The subdivisions of the body surface, and the corresponding weightings shown in Table 1 differ from those originally proposed by Hardy and DuBois only in that lumped values for arms and trunk were further subdivided in accordance with proposals of Blockley and Taylor (ref. 8), and ten skin temperature readings taken instead of seven.

The bioharness described in Volume I, part 2 of this report series was designed to provide the attachment of thermistors for these ten skin temperature positions as well as for the rectal probe attachment. A detail of the thermistor attachment and bioharness is shown in Figures 17 and 18.

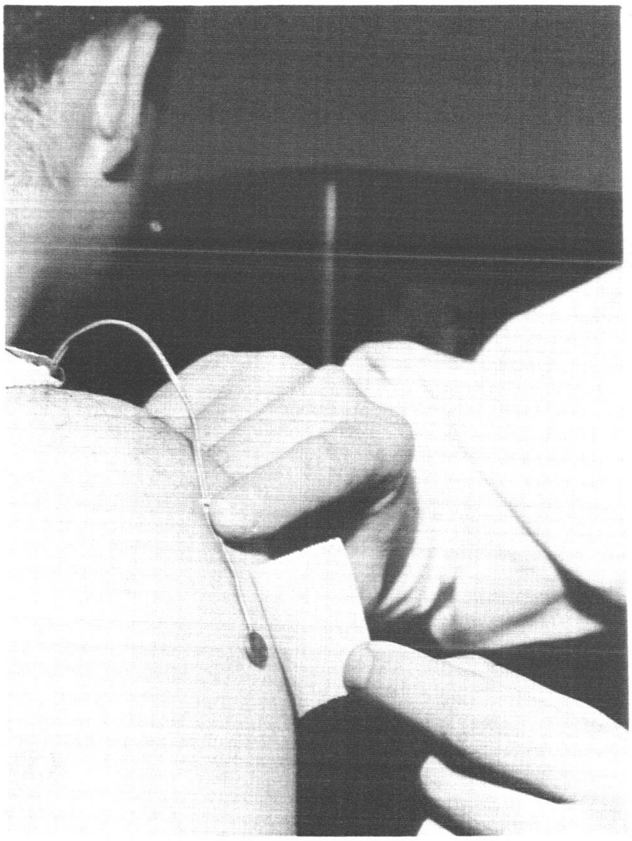


Figure 17.- Attachment of skin thermistors

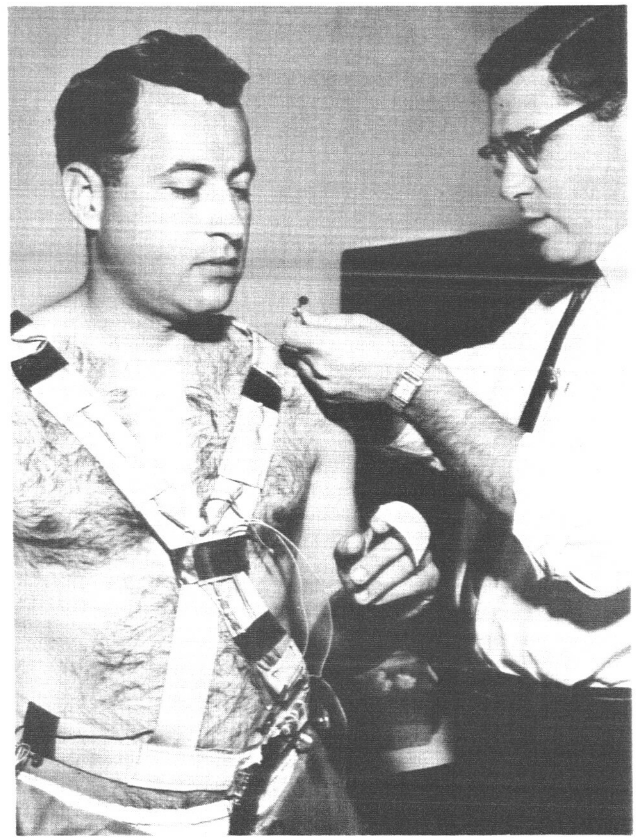


Figure 18.- Subject preparation

Rectal temperature was measured by a rectal thermistor probe, inserted to a depth of six in. by the subject during his pre-test preparation. Skin and rectal temperatures were then weighted and combined into a mean body temperature.

Temperature readouts were provided by the meter at the lower left of the monitoring panel shown in Figure 3, together with temperatures at suit inlet and outlet.

The following two formulas describe the method of weighting the skin temperatures into a mean skin temperature.

$$t_{SF} = t_s \cdot F_w$$

t_{SF} = Skin temperature fraction (°F)

t_s = Skin temperature of anatomical region (°F)

F_w = Weighting factor of anatomical region

$\bar{t}_{sw} = \Sigma t_{SF}$ (of all anatomical regions)

$\bar{t}_{sw}$ = Mean weighted skin temperature

Rectal temperature weighting along with the mean skin temperature provides the mean body temperature according to the following formula:

$$\bar{t}_b = .33\ \bar{t}_{sw} + .67\ t_r$$

$\bar{t}_b$ = Mean body temperature (°F)

t_r = Rectal temperature (°F)

Physiological "Steady State"

When the energy-exchange level of any activity is changed, some time is required before the various physiological systems of the body adjust to the new conditions. Where possible, it is desirable to make measurements while the body is in a "steady state" of functioning in terms of heart rate, respiratory rate and volume, and oxygen consumption, at each activity level. At light to moderate work levels, without external thermal stress conditions, a steady state satisfactory for physiological measurements generally develops within 5 minutes or less. Under heavy to maximal work loads, or when appreciable unbalance between heat production and heat loss exists, a true steady state is never achieved. One aspect of this is that when energy requirements are not met by maximal oxygen intake, the body must depend in part upon non-oxidative breakdown of body energy stores in the form of glycogen: a process known as anaerobic metabolism. An "oxygen debt" develops, requiring cautious interpretation of oxygen consumption patterns in the near-maximal range of physical activity. The other aspect is that heart rate is affected not only by oxygen transport requirements in support of metabolic processes, but also by rise of body temperature during storage of heat when heat loss does not balance heat production. In such a situation, heart rate will continue to rise even when oxygen consumption has stabilized and no "oxygen debt" is developing.

During this research program, the preconditioning and familiarization period was used for preliminary evaluation of some of the more strenuous task levels. This permitted planning of the test sessions and data-collecting procedures during the experimental program withdue allowance for steady-state requirements.

Computer Program

For determination of average body temperature, and calculation of metabolic rates from the Mueller-Franz Respirometer and gas analysis data, extensive computational procedures were required which were well suited to computer processing and readout. In the case of body temperature, this involved weighted averaging of eleven temperature measurements at least once for each individual test period, of which there were hundreds. The metabolic determinations required the following.

(1) Correction of gas volumes for temperature and barometric pressure.

(2) Estimation of the RER from the O_2 and CO_2 analyses.

(3) Use of a caloric equivalent for O_2, based on the RER.

(4) Calculation and listing of the actual metabolic rate in Btu/hr.

(5) Calculating of the equivalent rate for a "standard man."

(6) Calculation of the metabolic rate per unit body surface area, in kilo-calories per square meter per hour.

The "standard man" was assumed to have a surface area of 1.80 square meters. This would be the surface area of a man with a height of 67.5 in. (172 cm) and a weight of 150 lb (68.3 kg) though, of course, other combinations of height and weight provide the same estimated surface area.

Information on the setting up, use and interpretation of the computer program is contained in Appendix B. The printout included related environmental temperature and barometric pressure information, with the corresponding gas volume correction factor.

PROCEDURES

Test Session Scheduling

A typical test session required a schedule time of half a working day -- morning or afternoon. Testing of one subject in both morning and afternoon sessions was attempted. but abandoned due to a number of problems involving both the subject and the test crew. Subjects proved to be in definitely better condition in the morning. Unless a basal test was required, with the subject in post-absorptive condition, breakfast was allowed. Each subject was encouraged to standardize on a light breakfast of his own choice. Departure from a "standard" meal was found to produce no apparent effect except sometimes to elevate the RER if carbohydrate intake (such as sugar in coffee) was unusually high. It was found that the work physiological data produced by the subject closely after a meal (especially at noon) became questionable. Fatigue produced by the procedure also exerted some effect on an afternoon session if preceded by one in the morning. Furthermore, removal of the cardiac electrodes at the end of a day resulted in undue tissue irritation (and sometimes tissue removal) which made a full test day an unacceptable practice. Most tests were therefore run in the morning. The extreme concentration and cooperation of the members of the test crew, required for successful conduct of a session, was markedly

decreased in afternoon sessions, and resulted in errors of data recording and other human errors. Morning sessions were much more uniformly successful, and most tests started about mid-morning.

Subject Preparation and Pretest Checkout

Prior to each test session, the subject was checked and his condition recorded on a data sheet. Data recorded included information on the last prior meal, his body temperature, heart rate, and general condition including any unusual aspects of activity or food intake for the prior evening. The bioharness was then installed. Figure 18 showed a subject in process of harness installation. Details of cardiac rate sensor and thermistor placement are shown in Figures 11, 12 and 17. Figure 19 shows a full front view of a subject in the bioharness.

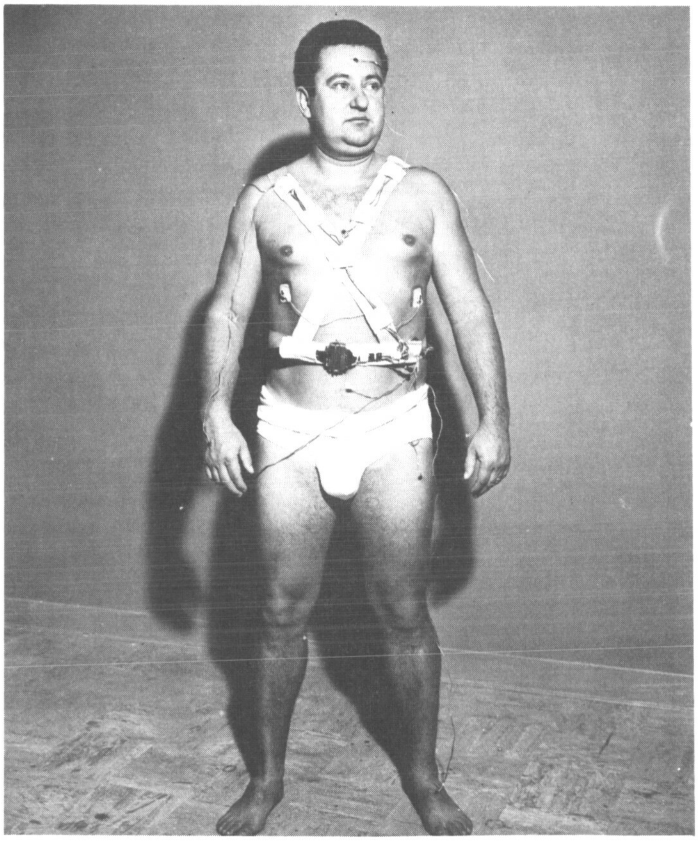


Figure 19. - Subject in bioharness

The cardiac rate sensors are a few inches below each nipple (a ground electrode is in back). Thermistors may be seen in several locations. On the front of the belt is the multiple connector for the biomedical circuitry.

If the test was to include the pressure suit, this was donned, after which the support harness was installed. Then, shortly before the actual test procedure started, an ECG check was made in the laboratory, as shown in Figure 20. In the early stages

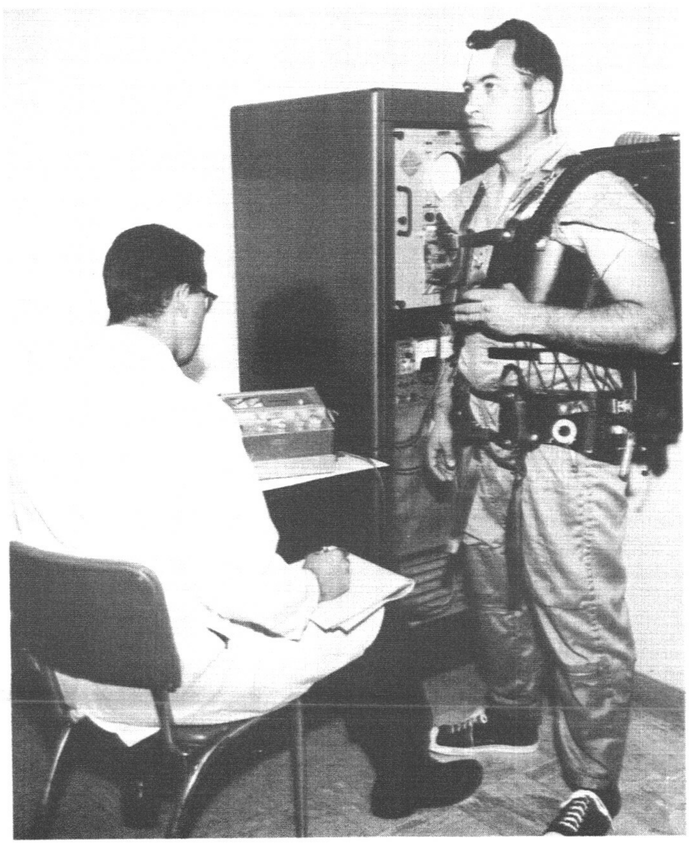


Figure 20. – ECG pre-test check out

of the project, a post-test ECG check was also made, but soon found unnecessary. Pulse counts by manual palpation were made during the period of validation of the heart rate indicating and recording instrumentation, but were abandoned when it became evident that they were redundant.

Test Procedure

Although the procedure necessarily varied somewhat depending on the purpose of each test session and the nature of the physical activity involved, much procedure was common to all tests. Typically, a series of individual tests were performed during each test session. The first set of readings would be taken with the subject at rest (standing) to provide a "base line" for that session. Following this determination, a series of tests would be performed, spaced by short rest periods, and generally in order of increasing level of energy expenditure. Each would be continued for a sufficient length of time to achieve the "steady state" previously discussed. This was judged by reaching substantially constant heart and respiration rate readings as indicated on the tachometer meters for each. An average test had a duration of from 5 to 10 minutes and sometimes longer.

The duration of a complete test session depended on the number of individual tests (usually from 3 to 5) and ranged from about 60 to about 90 (sometimes 120) minutes for "shirt-sleeve" tests. Some of the pressure suit test sessions reached as much as 160 minutes' duration. Maximum duration was based on not exceeding the tolerance of the subject in terms of his physiological reactions. A heart rate of 180 beats/minute was the accepted endpoint for a test. Because of lag in the tachometer indication, it was occasionally found from the graphic record that the rate went as high as 200 beats/minute before starting to decline during the post-exercise period.

Baseline Tests

Since one of the principal purposes of the physiological observations made in this program was to evaluate the relative effects of various conditions and activities, establishment of baseline values for use in these comparisons was necessary. Typical baseline observations were made under the following conditions.

(1) Occasionally with the subject in the "basal" state, i.e., lying at rest in the postabsorptive state.

(2) With the subject standing at rest relative to normal earth gravity and then relative to the simulated lunar gravity. Observations of this kind were routinely made at the beginning of a test in any mode, with whatever clothing or equipment required for that test.

(3) Another type of baseline was the series of data points obtained for a given procedure under earth gravity, to enable comparison with the same procedure on the LGS.

Figure 5 shows a gasometer kymographic chart record of a baseline test at one g, and illustrates the subject's respiratory response in a series of tests progressing from rest to walking at speeds up to four mph on the treadmill. The subject exhaled into the gasometer; the bell rises a distance proportional to the volume of each exhalation and the total rise per minute is a measure of the exhaled minute volume of lung ventilation ($\dot{V}_E$). The arrangement of the recording system is such that when the chart is removed from the kymograph for review, the progressive increase in collected exhaled air is measured on the ordinate, with time on the abscissa. Since the gasometer bell does not move while the subject inhales, the line is horizontal during that period, giving the tracing its characteristic step-like appearance.

Each of the six tracings shown on this chart begins at the bottom, and slants upward to the right. The slope of the trend-line of the tracing is a measure of the lung ventilation rate at that time, which may be expressed in any convenient unit, such as liters or cubic meters per minute. Each vertical line on the grid indicates 1 minute, and the rise of the tracing in a given period thus is a measure of the ventilation rate

per minute when divided by the number of minutes. Volumes are calculated from the line rise in millimeters, multiplied by the bell calibration factor (volume per mm), in this case 133 ml per mm.

The effect of the progressively-increasing energy expenditure level on ventilation is seen in terms of the progressively-increased slopes, as the subject went from rest to the four mph walking rate. Note in particular that ventilation actually declined slightly during the six minutes of sitting at rest. This is typical of the body's adjustment to rest after prior activity. Note also that the ventilation rate when standing at rest was practically constant and substantially the same as when sitting. At the higher walking speeds, the ventilation rate increased slightly as each test progressed.

Environmental Temperatures

The ambient thermal conditions were evaluated in terms of the globe temperature. The globe thermometer used is described in Volume I, Part 2 in Instrumentation. In tests in the earth gravity mode, the globe thermometer was located so as to be near both the subject and the instrument pack containing the respiration meter. When the LGS was used, the globe thermometer was located on the catwalk above the subject's test area, as shown in Figure 24 of Volume I, Part 2.

Figures 21 and 22 show the subject in his suspension gear on the LGS.

In experiments involving use of the pressure suit, the temperature of the ventilating air flow at suit inlet and outlet was also recorded. Since the tests were conducted outdoors, the test log also recorded the weather conditions.

Figure 21.- Shirtsleeve test series 1000

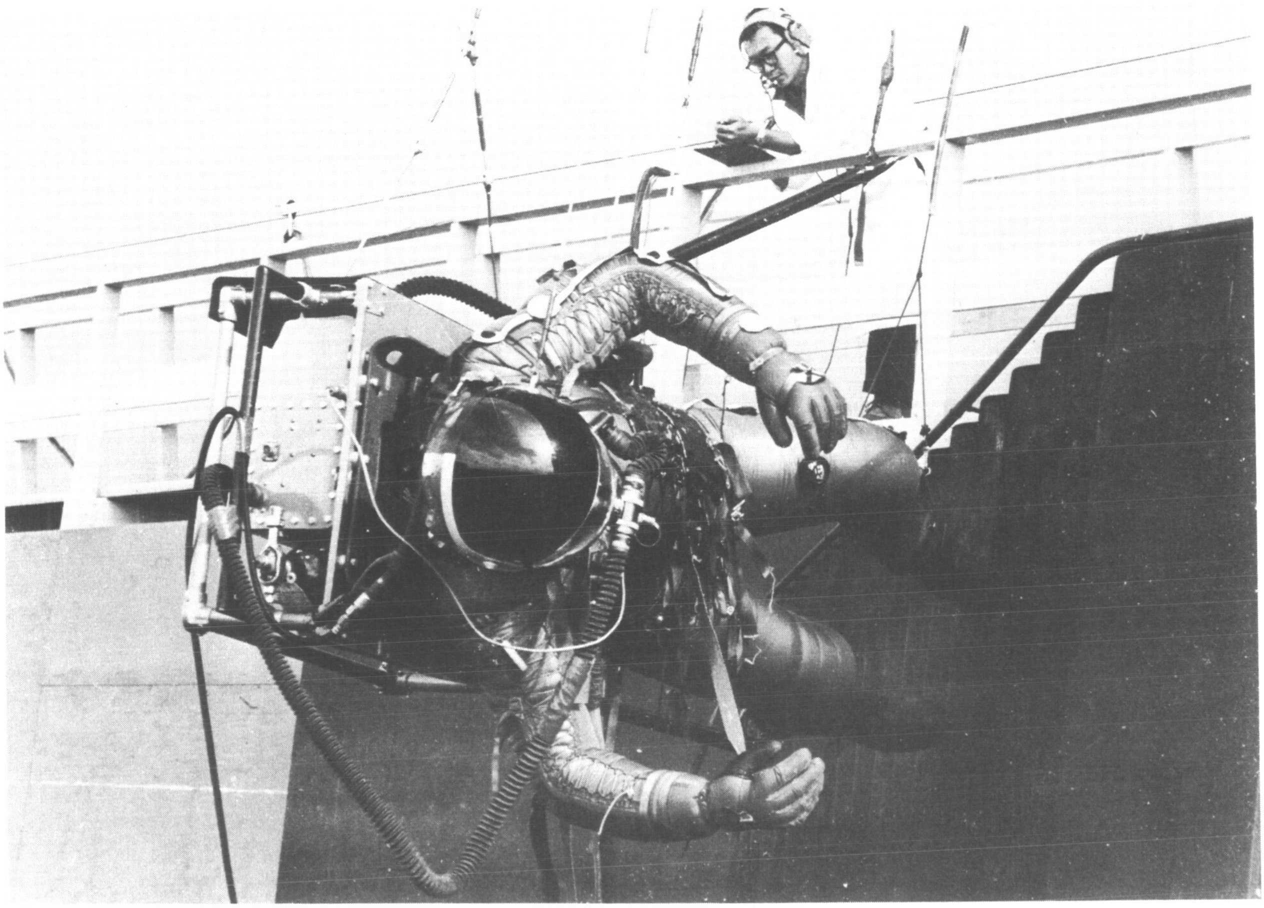


Figure 22.- Pressure suit test series 3180

RESULTS

The results of this study are presented as a series of data records and curves of experimental data following the established test identification numbers in tables 2 through 4.

Each test series or group of test series is preceded by a cover sheet. Described in one paragraph are the test conditions. These indicate the type of work activity and work variable investigated. It further states under what gravitational environment the test series was conducted and on what facility. If available an illustration of the specific test set up was provided or referenced.

The second paragraph entitled "test results" shows the number of test subjects used and the number of tests performed by each individual subject in the series. This is followed by a listing of the data recorded, analyzed and presented in tabular or curve form.

The collection of curves is arranged according to their activity and follows the previously mentioned sequence which will aid in the comparison of the physiological parameters measured.

For each individual test series in each major mode, curves plotted as a function of subject velocity are included for the following work physiological data:

(1) Respiratory rate, breaths/min

(2) Respiratory volume expired, liters/min

(3) Metabolic energy expenditure rate, kcal/h and Btu/h

(4) Metabolic energy expenditure per unit length, kcal/m and Btu/ft

(5) Oxygen consumption, liter/min and cu ft/min

(6) Oxygen consumption per unit length, liter/m and cu ft/ft

(7) Cardiac rate, beats/min

(8) Mean body temperature, degrees F and degrees C

(9) Pressure suit environmental data

Each data point in these curves for each subject at a given velocity represents either his average for that velocity (if more than one test was run) or a single observation made during the presumed steady state. The average or trend-line for each graph was located through points representing the averages for the data points for the several subjects at each velocity, except where specific allowance has had to be made for known disturbing factors, especially environmental temperature.

The graphs for minute volume of lung ventilation were plotted from data which has been corrected to standard conditions (Standard Temperature and Pressure Dry, STPD). In the case of the data obtained during the pressurized suit test series, conducted at an

TABLE 2 SUMMARY OF WORK PHYSIOLOGY BASELINE
TEST MODES AND SERIES CONDUCTED

Work Classification Non-Performance Work		Mode 5000 Shirt Sleeve 1/6 g - No Instrument Pack				Mode 5500 Shirt Sleeve 1g - No Instrument Pack				Mode 6000 Shirt Sleeve 1g - Susp. Gear & Inst. Pack I			
Work Activity	Work Variable	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C
Walking	Horizontally	5000(66)	8		8	5500(73)	27	6	12	6000(80)	6	6	12
	Ascending (Max. Grade)	5020				5520				6020(134)	4		11

Work Classification Non-Performance Work		Mode 6500 Shirt Sleeve 1g - Suspension Gear Only				Mode 7000 Pressure Suit-Vent Flow 1g - Instrument Pack II				Mode 8000 Pressure Suit - 3.5 PSI 1g - Instrument Pack II			
Work Activity	Work Variable	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C
Walking	Horizontally	6500(88)	6		12	7000(95)	6		6	8000(103)	3		3

Note: The test results for each of the tests conducted can be found by the page number given adjacent to the series number of tests in Tables 2 and 3.

TABLE 3 SUMMARY OF WORK PHYSIOLOGY TEST MODES AND SERIES CONDUCTED ON LUNAR GRAVITY SIMULATOR

Work Classification Non-Performance Work		Mode 1000 Shirt Sleeve Instrument Pack I				Mode 2000 Pressure Suit-Vent Flow Instrument Pack II				Mode 3000 Pressure Suit - 3.5 PSI.* Instrument Pack II			
Work Activity	Work Variable	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C	Series	Subject A	Subject B	Subject C
Walking	Horizontally	1000(34)	12	16	13	2000(44)	9		12	3000(55)	7		13
	Ascending (Max. Grade)	1020(111)	9	5	7	2020(120)			7	3020(127)			5
		1030(141)	7	6	6	2030(150)			6	3030(157)			3
		1040(164)	5		5	2040				3040			
	Descending (Max. Grade)	1050(173)	8		5	2050(182)			5	3050(189)			5
		1060(196)	3		3	2060				3060			
Jumping	Horizontally	1120(205)	17	7	5	2120(214)	4		4	3120(222)	4		4
Stepping on Stairs	Ascending and Descending	1180(230)	5	5	5	2180(240)			5	3180(250)			4
Loping	Horizontally	1200(260)	5		4	2200(269)	4		4	3200(277)	5		5
Crawling	Horizontally	1230(285)	6			2230				3230			

Note: The test results for each of the tests conducted can be found by the page number given adjacent to the series number of tests in Tables 2 and 3.

TABLE 4 SUMMARY OF INDIVIDUAL SUBJECT PARTICIPATION IN VARIOUS TEST MODES

	Total Number of Tests Per Subject for Each Mode		
	A	B	C
Lunar Series			
1000	77	39	53
2000	17	-	43
3000	16	-	39
Series Total	110	39	135
Baseline Series			
5000	8	-	8
5500	27	6	12
6000	10	6	23
6500	6	-	12
7000	6	-	6
8000	3	-	3
Series Total	60	12	64
Grand Total	170	51	199

absolute pressure 3.5 psi above atmospheric, this has resulted in minute volumes which are approximately 24 percent above parallel values obtained in the other series conducted at atmospheric pressure. These data should therefore not be compared directly with most lung ventilation volume data in the physiological literature, customarily expressed in terms of the volumetric exchange under the conditions of measurement (Body Temperature and Pressure Saturated, BTPS).

Curves for the metabolic energy expenditure per unit length and for the oxygen consumption per unit length were plotted for the purpose of establishing optimum locomotion velocities. In addition to yielding the optimum, these curves will provide useful information for the logistic support requirements of man when assigned lunar mision tasks. They will provide data for the cross-sectional sizing of lines in the life support and ECS equipment as well as the determination of life support and ECS capacities. It should be noted, however, that the plotted work physiological data was the result of tests conducted for relatively short durations with a maximum of 10 minutes. These tests did not include the effect of duration and fatigue when such experiments are conducted for prolonged periods of time and this aspect must be recognized.

In association with the figures showing average body temperature as a function of subject velocity in the various test modes and series, graphs have also been prepared to show the thermal environment of the subjects during the tests in which pressure suits were worn. The temperature relationships of experiments conducted in the pressure suit at a constant flow rate provide important data for the design of ECS

equipment. These graphs show the ambient temperature as measured by the globe thermometer, and the suit ventilating air temperatures at the suit inlet and outlet. These are plotted against subject velocity to conform to the other graph series in this report. The time of day at which the readings were taken is also indicated, both to illuminate the changes in ambient temperature during a test session, and the time factors in its effect on the suit ventilating air temperatures. These were of course also affected by the level of activity and heat production of the subject. These graphs follow the graphs of body temperature in the numerical groupings under each test mode.

In addition to the foregoing graphs on individual test series, summary graphs have been prepared. These have been cross-plotted to provide comparison, for instance, of the oxygen consumption curves under various test conditions. The summary curves will be included in the Discussion section which follows.

The third paragraph reserved a smaller space for some on-the-spot comments particular to the test series.

Test Identification Numbers

Originally the test program was perted whereby each test was identified by a part number. Because of sudden changes sometimes necessary in the test schedule, a different method of test designation was adopted in the initial phase of the test program. A typical sample and explanation of the test identification number is shown in Figure 23.

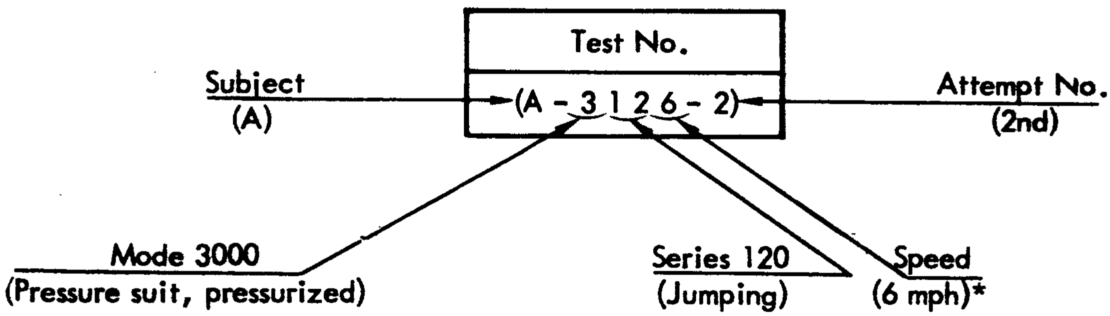


Figure 23. - Test identification numbers

*This number does not always directly indicate the speed, since some test series started with standing at rest, followed by a test at 0.5 mph. Thus a number 7 would stand for 5 mph.

In addition to the major series number coding, distinguishing terminal 2- and 3-digit combinations were also assigned to conditions or activities common to all series, as follows:

(1) xx00 -- Walking and running horizontally
(2) xx20 -- Same, ascending at 10° grade
(3) xx30 -- Same, ascending at 20° grade
(4) xx40 -- Same, ascending at 30° grade
(5) xx50 -- Same, descending at 10° grade
(6) xx60 -- Same, descending at 20° grade
(7) x120 -- Jumping horizontally
(8) x130 -- Jumping vertically up
(9) x140 -- Jumping vertically down
(10) x150 -- Jumping horizontally down

(11) x180 -- ascending and descending stairs
(12) x200 -- Loping horizontally
(13) x230 -- Crawling horizontally

Curve Plot Symbols

Since most of the test results are presented by data points on individual or summary curve plots, it became necessary to assign meaningful curve plot symbols. These are defined in Table 5. These symbols have been based on those specified in NASA Publications Manual, NASA SP-7013. Because of the great number of data point and line symbols required, some additional ones had to be established. This was done by expanding those recommended in the NASA Publications Manual.

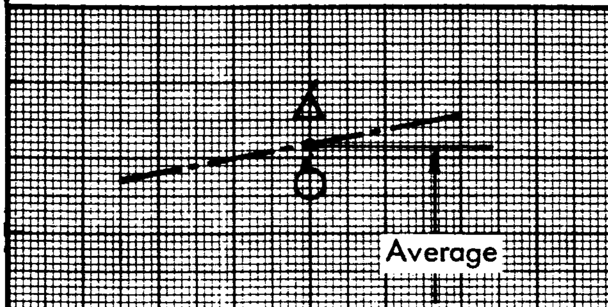
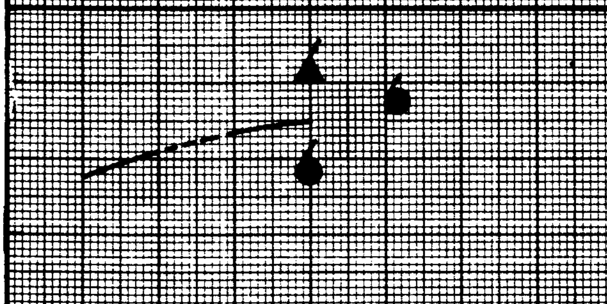
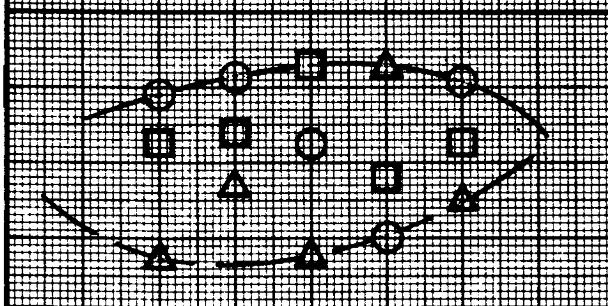
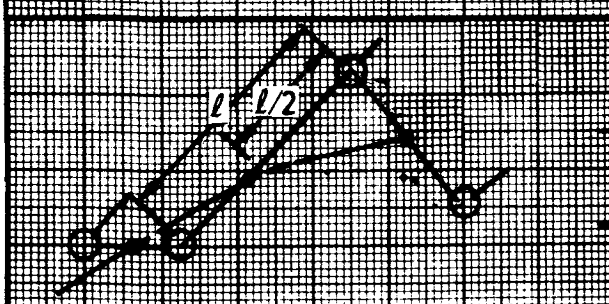
TABLE 5. CURVE PLOT SYMBOLS

	Test Series	Line Symbol	Subject A	Subject B	Subject C	Description
Lunar, series	1000	— — — —	○	□	△	Shirt Sleeve, instrument pack I
	2000	—— - ——- —	○	□	△	Pressure suit, vent flow, instrument pack II
	3000	—— ·· —— ·· —	○	□	△	Pressure suit, pressurized, instrument pack II
	4000	——— - - - ——	○	□	△	Pressure suit, pressurized, instrument pack III
	5000	——— - - - - ——	○	□	△	Shirt sleeve, no instrument pack
Earth, series	5500	—— - ——-	●	■	▲	Shirt sleeve, no instrument pack
	6000	————	●	■	▲	Shirt sleeve, suspension gear, instrument pack I
	6500	—— -- —— --	●	■	▲	Shirt sleeve, suspension gear only
	7000	—— ··· ——	●	■	▲	Pressure suit, vent flow, suspension gear, instrument pack II
	8000	—— ···· ——	●	■	▲	Pressure suit, pressurized, suspension gear, instrument pack II

It can be seen that the open symbols are used to define the experiments conducted under simulated lunar gravity while the full symbols indicate the experiments conducted under earth gravity. The symbol expansion itself signified the type of test conditions. Two identical symbol expansions, but one in full and the other open, indicate that the same test conditions prevailed in both tests and only varied by the gravitational environment.

Although the data was presented according to the requirements of NASA Spec. SP-7013, certain special conditions still occurred in the drawing of data curves which warrant a separate explanation. Table 6 is used to provide this explanation.

TABLE 6 — DATA CURVE INTERPRETATION

	The commonly used average between 2 or 3 data points representing different subjects was used to determine the data curve.
	The average data curve stopped when no more averages were obtainable. Single data points though obtained during testing were still shown.
	When data points were distributed at random so called data rough curves were drawn which covered the external envelope of the data points.
	Sudden changes in the slope of the data curve pointed out such characteristic changes as the point of change over from walking to running.
	For drawing of a data curve through erratic data points, curve smoothing was applied by connecting the data points with straight lines and dividing their distance into two halves, thus locating the midpoint for the modified data curve. This curve will terminate at the last midpoint as shown.

The data point for each subject at a given velocity represents either his average for that velocity (if more than one test was run) or a single observation made during the presumed steady state. The average or trend-line for each graph was located through points representing the averages for the data points for the several subjects at each velocity.

Test Series 1000

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking and running	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	12	16	13

Respiration,	respiratory rate	Figure 25 *
	respiratory volume expired	Figure 26
Metabolism,	metabolic energy expenditure rate	Figure 27 **
	metabolic energy expenditure rate per unit length	Figure 28 **
	oxygen consumption	Figure 29 **
	oxygen consumption per unit length	Figure 30 **
Cardiovascular function,	cardiac rate	Figure 31
Body temperature,	mean body temperature	Figure 32
Pressure suit environmental data		Not Obtained

Comments:

The arrangement for the test conducted in this series is shown in Figure 24.

*The lower respiratory rate of subjects A and B at 7 mph than at 6 mph may be due to the second wind phenomenon.

**Figures 27 through 30 were modified according to intermediate averages.

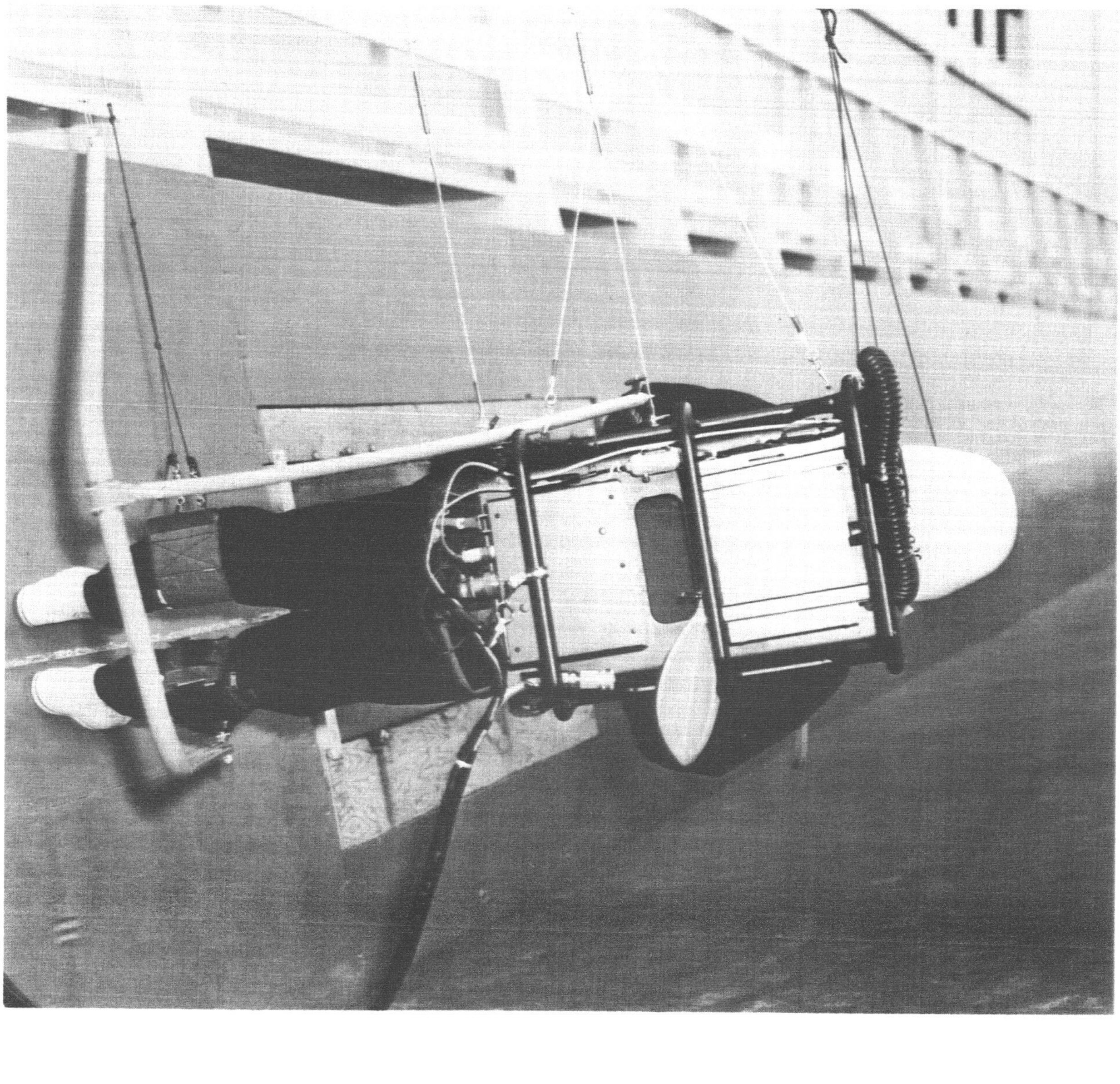


Figure 24. - Illustration of test arrangement for test series 1000

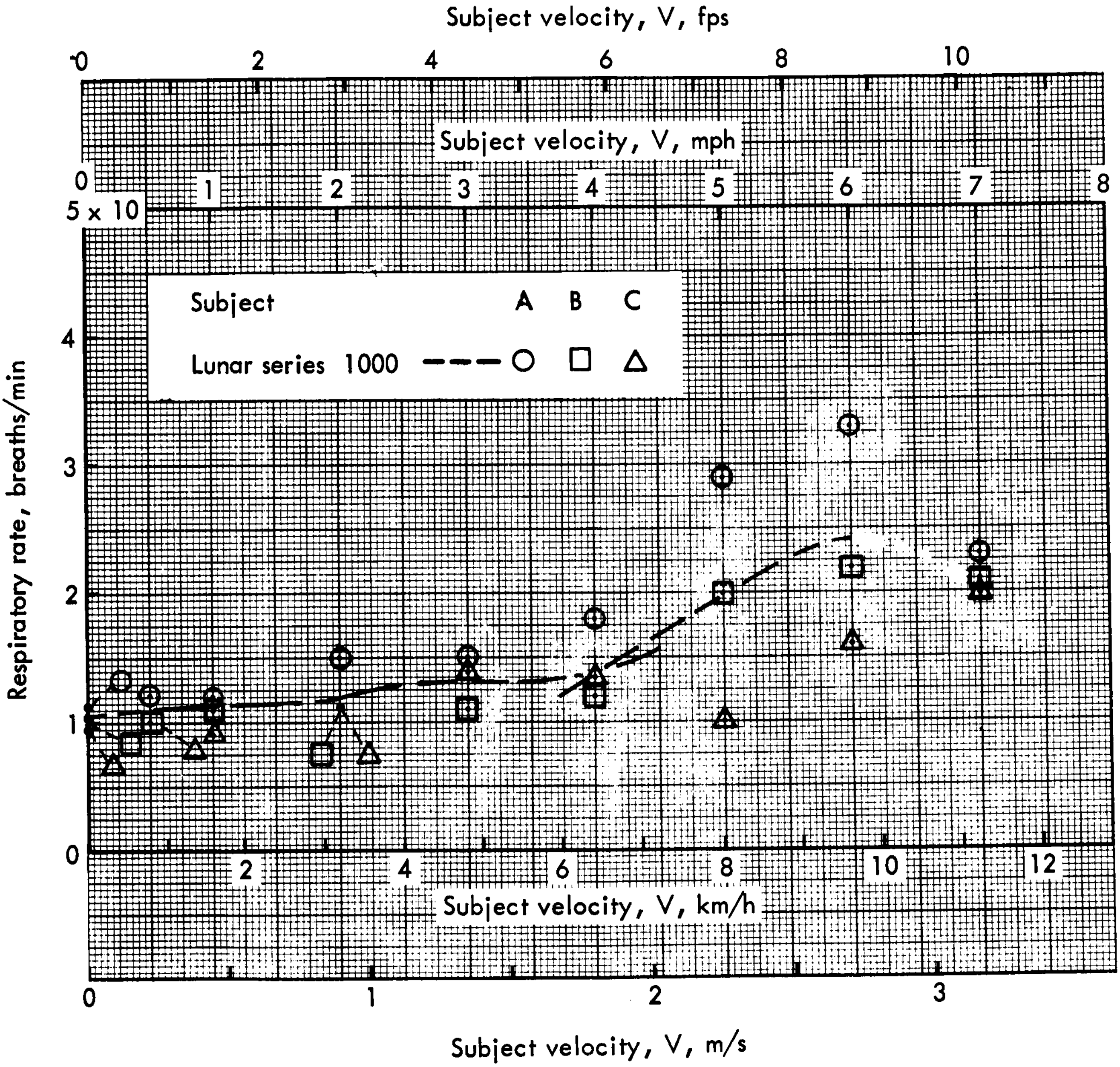


Figure 25. – Average respiratory rate versus subject velocity walking and running horizontally.
Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

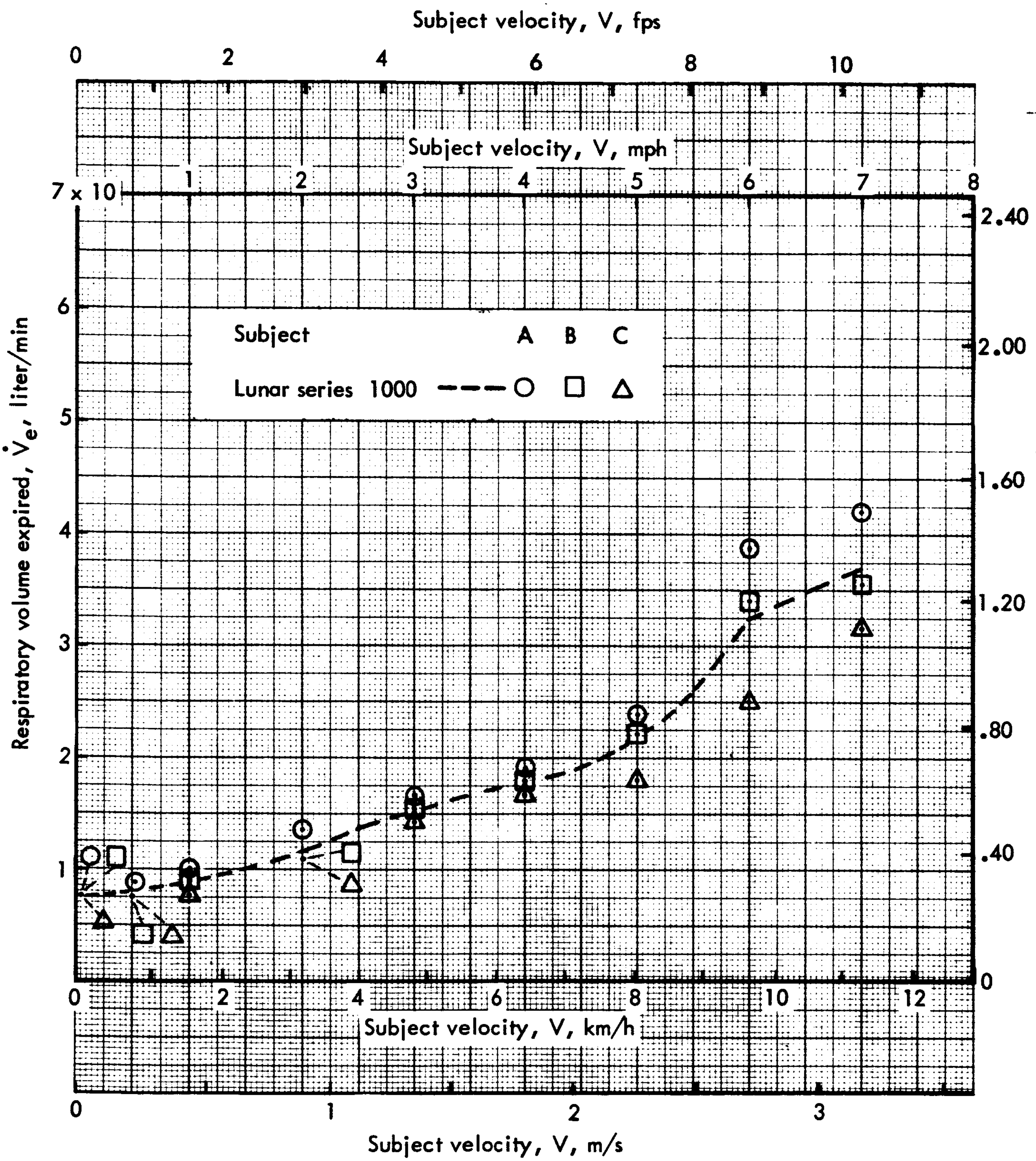


Figure 26. – Average mean respiratory volume versus subject velocity walking and running horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

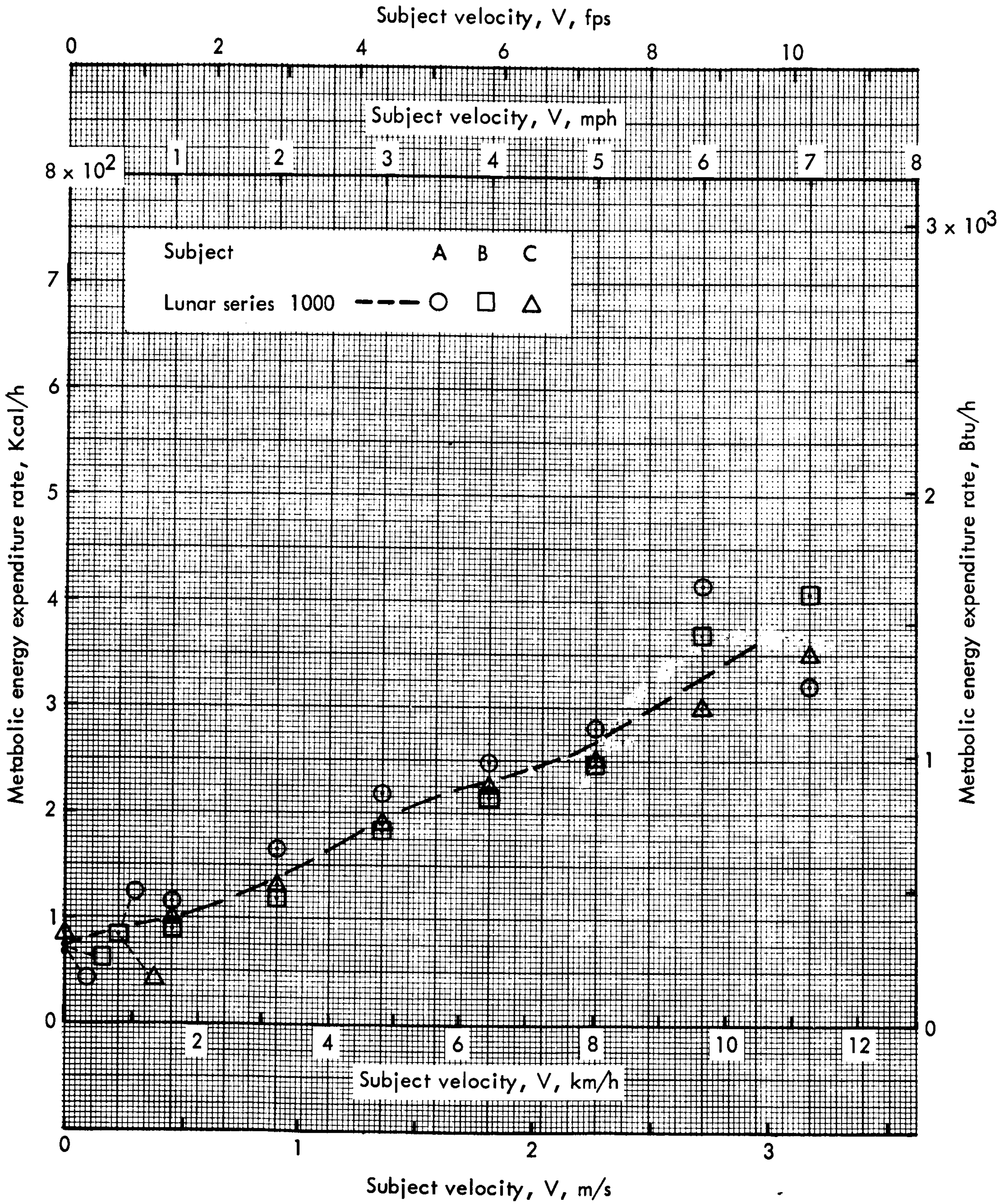


Figure 27. – Average metabolic energy expenditure rate versus subject velocity walking and running horizontally.
Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

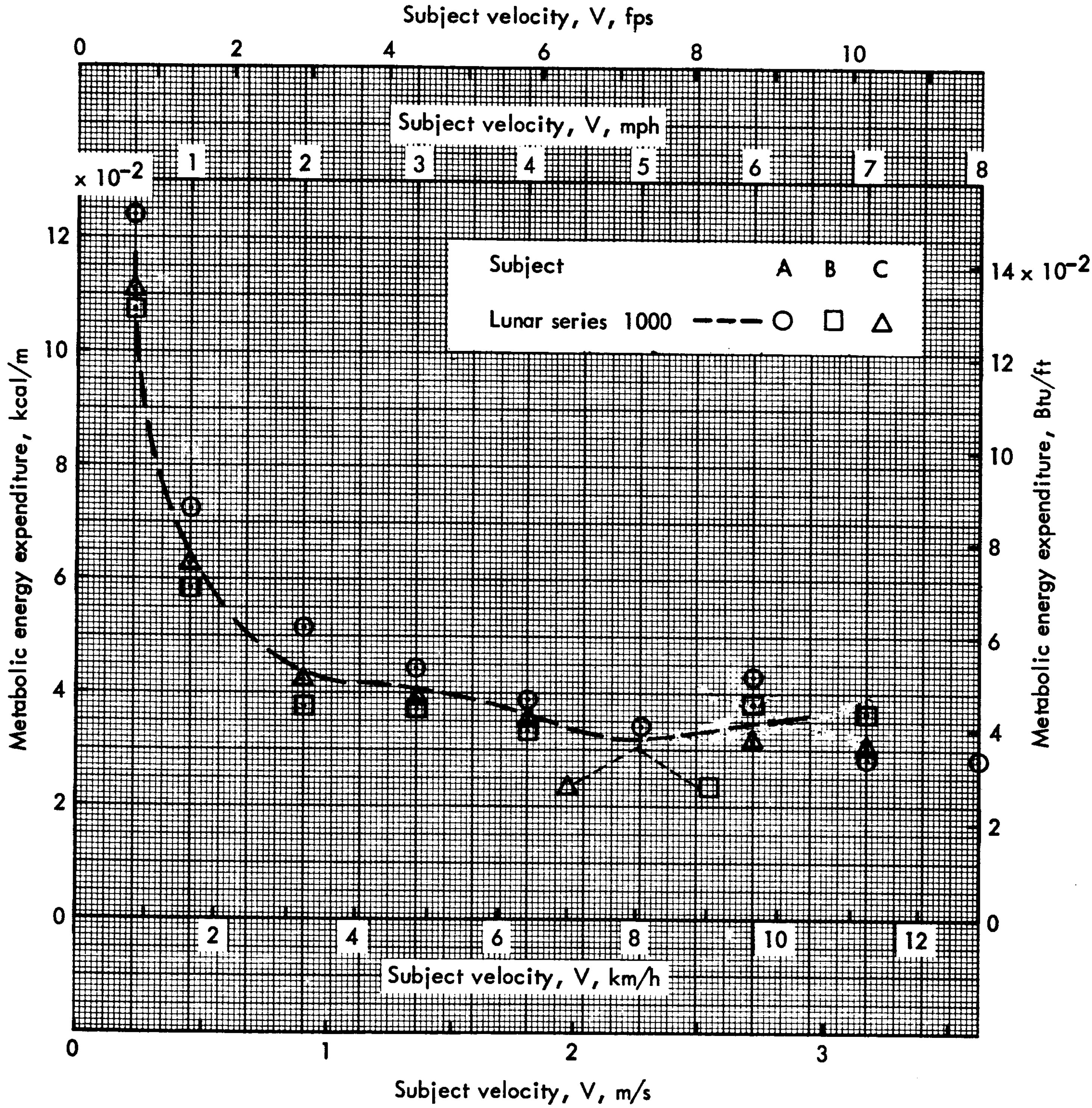


Figure 28. – Average metabolic energy expenditure per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

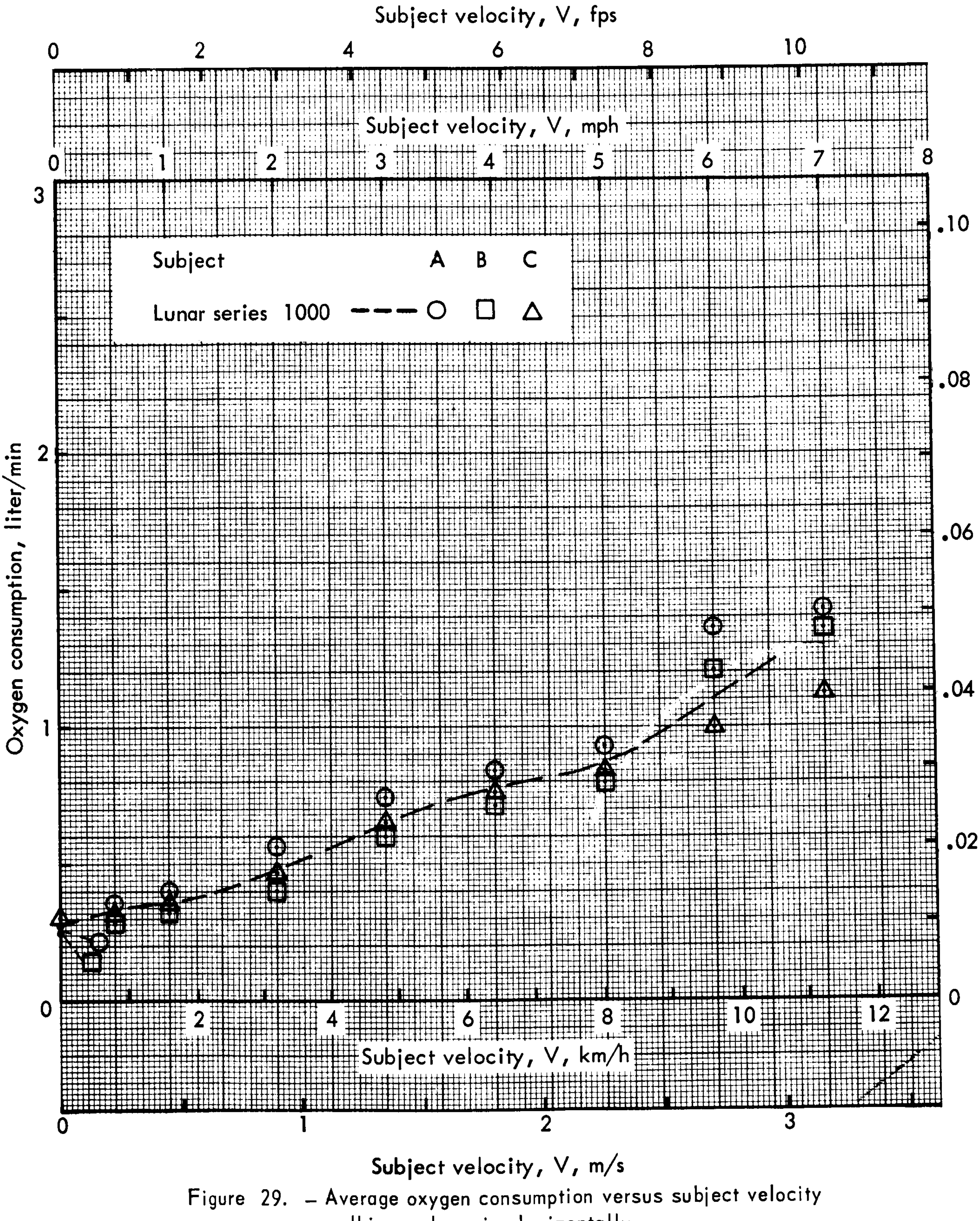


Figure 29. – Average oxygen consumption versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

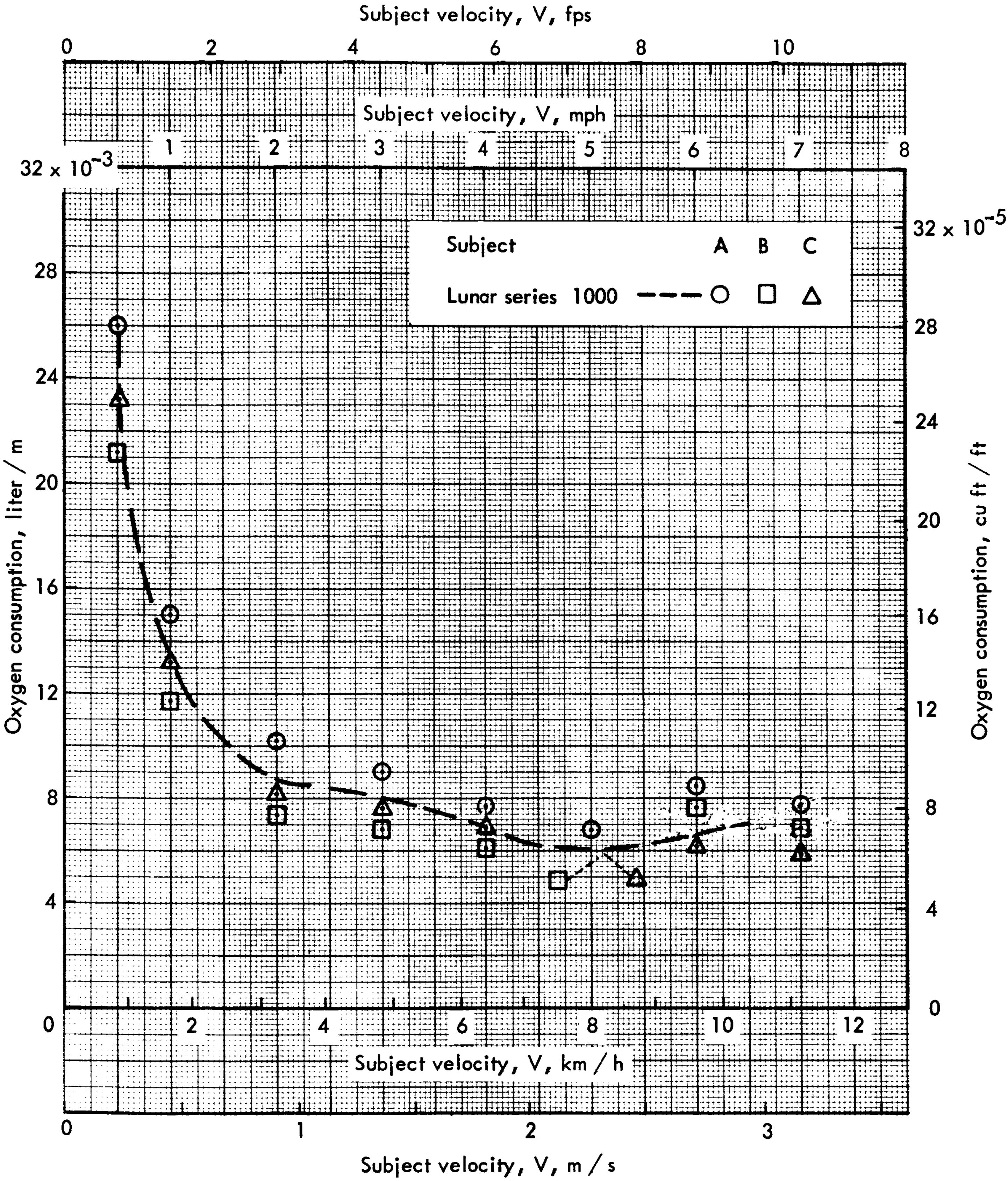


Figure 30. – Average oxygen consumption per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

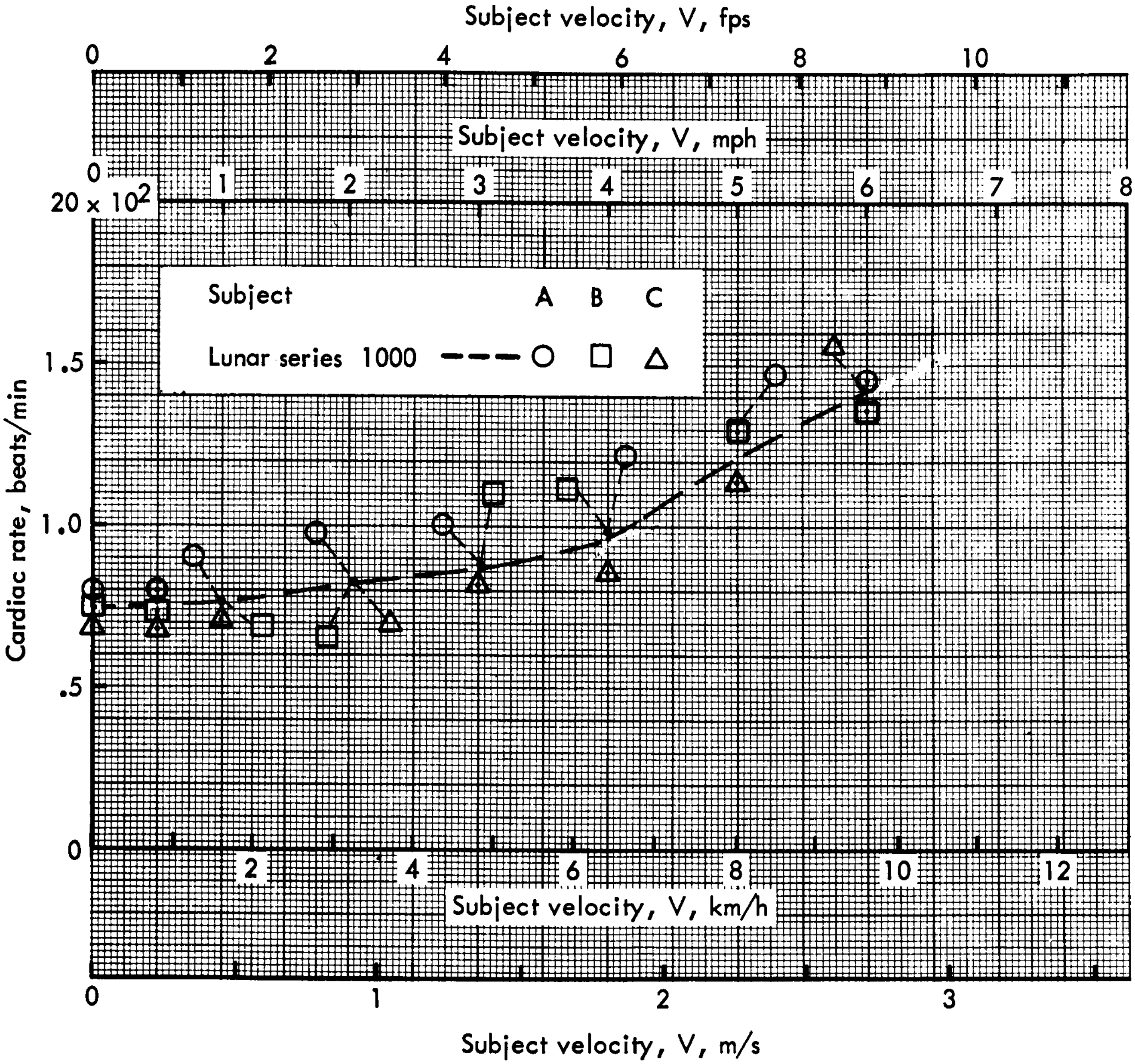


Figure 31. – Average cardiac rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

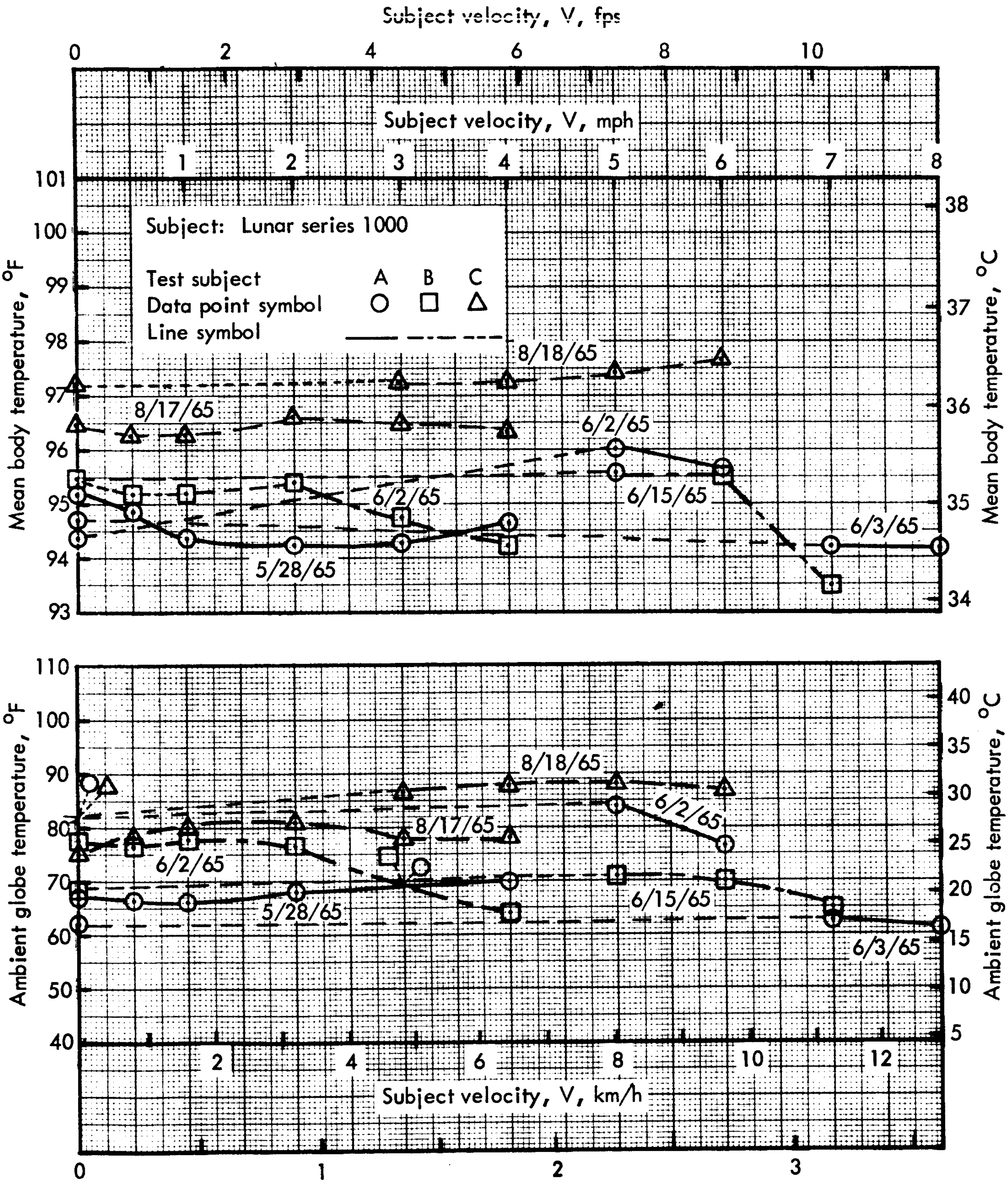


Figure 32. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2000

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	walking and running	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	9		12

Respiration, respiratory rate	Figure 34*
respiratory volume expired	Figure 35
Metabolism, metabolic energy expenditure rate	Figure 36
metabolic energy expenditure rate per unit length	Figure 37
oxygen consumption	Figure 38
oxygen consumption per unit length	Figure 39
Cardiovascular function, cardiac rate	Figure 40**
Body temperature, mean body temperature	Figure 41
Pressure suit environmental data	Figure 42

Comments:

The arrangement for the tests conducted in this series is shown in Figure 33

*Respiratory rate for Subject A could not be obtained beyond 4 mph

**Figure 40 was modified according to intermediate averages
Cardiac rate for Subject A at 5 mph was not obtained

Figure 33. – Illustration of test arrangement for test series 2000

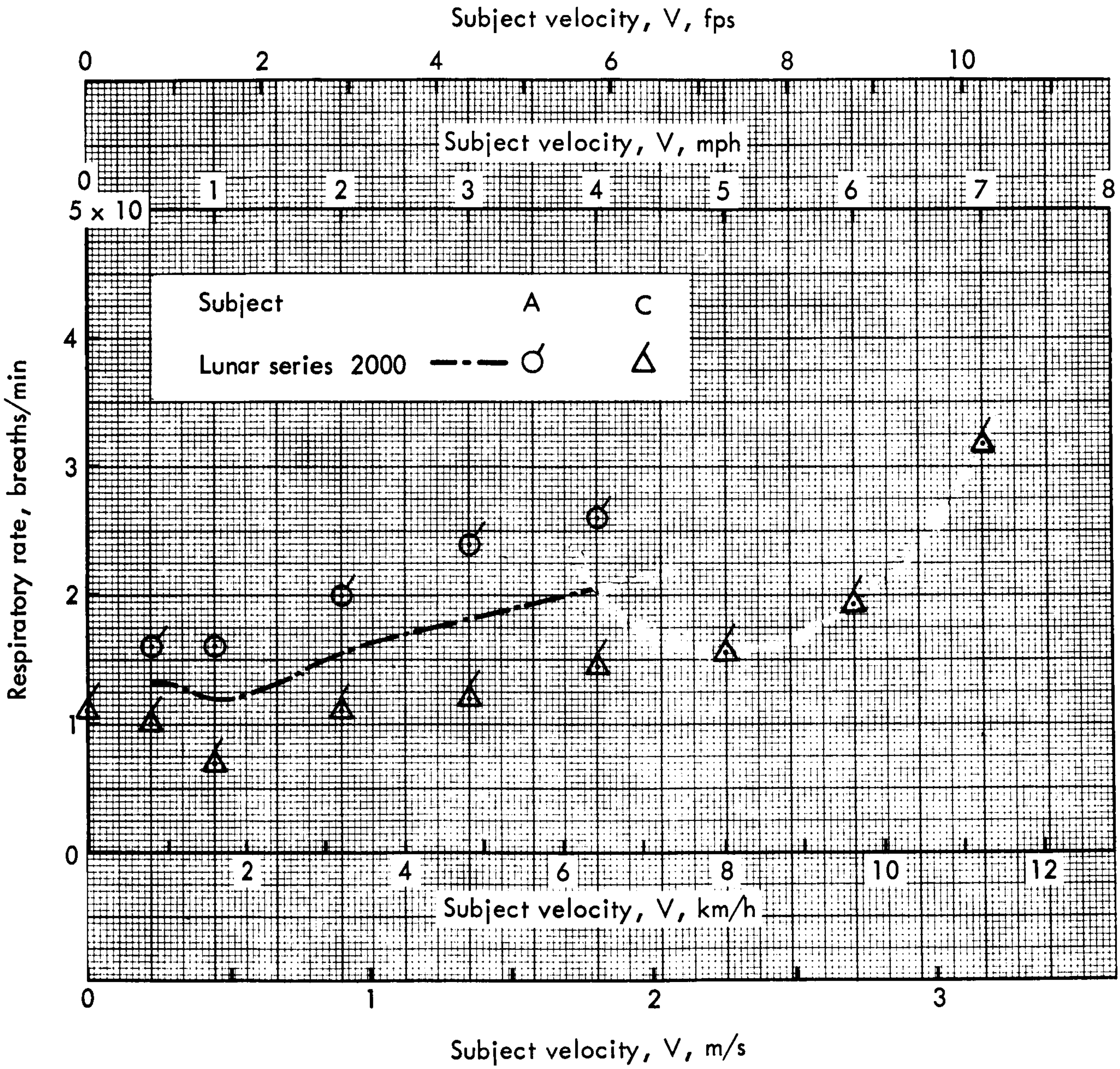


Figure 34. – Average respiratory rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

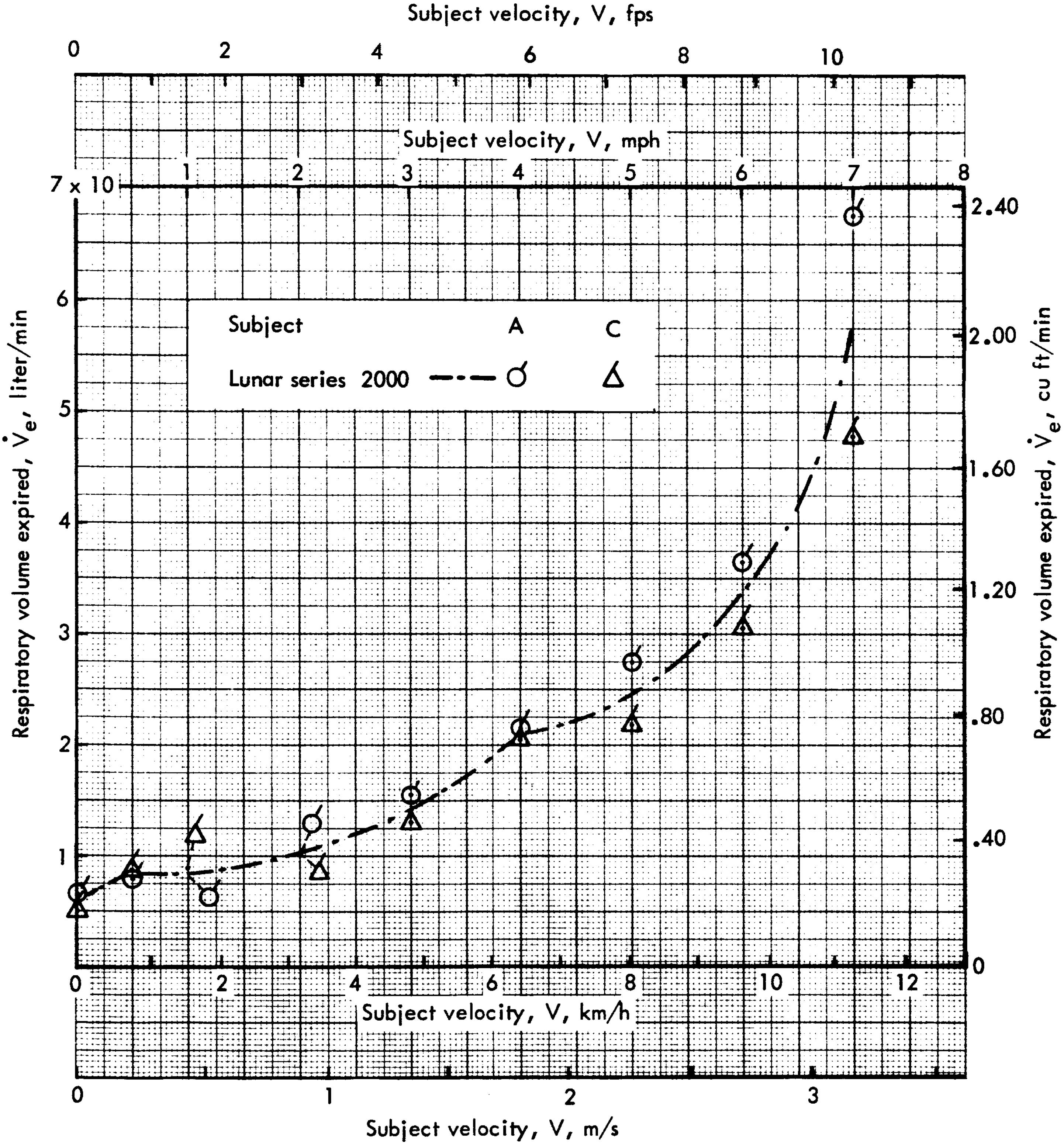


Figure 35. – Average mean respiratory volume versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

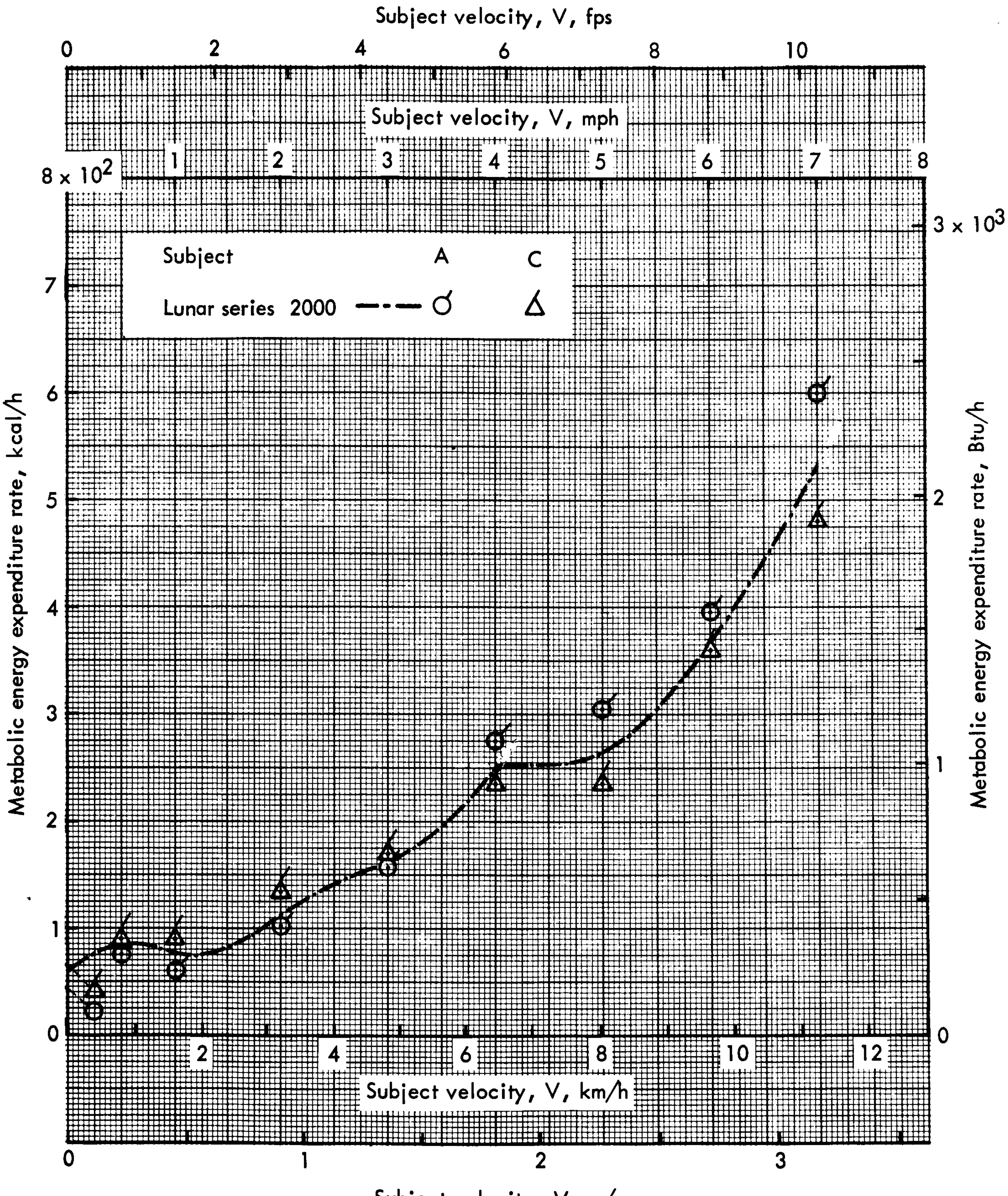


Figure 36. – Average metabolic energy expenditure rate versus subject velocity walking and running horizontally.
Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

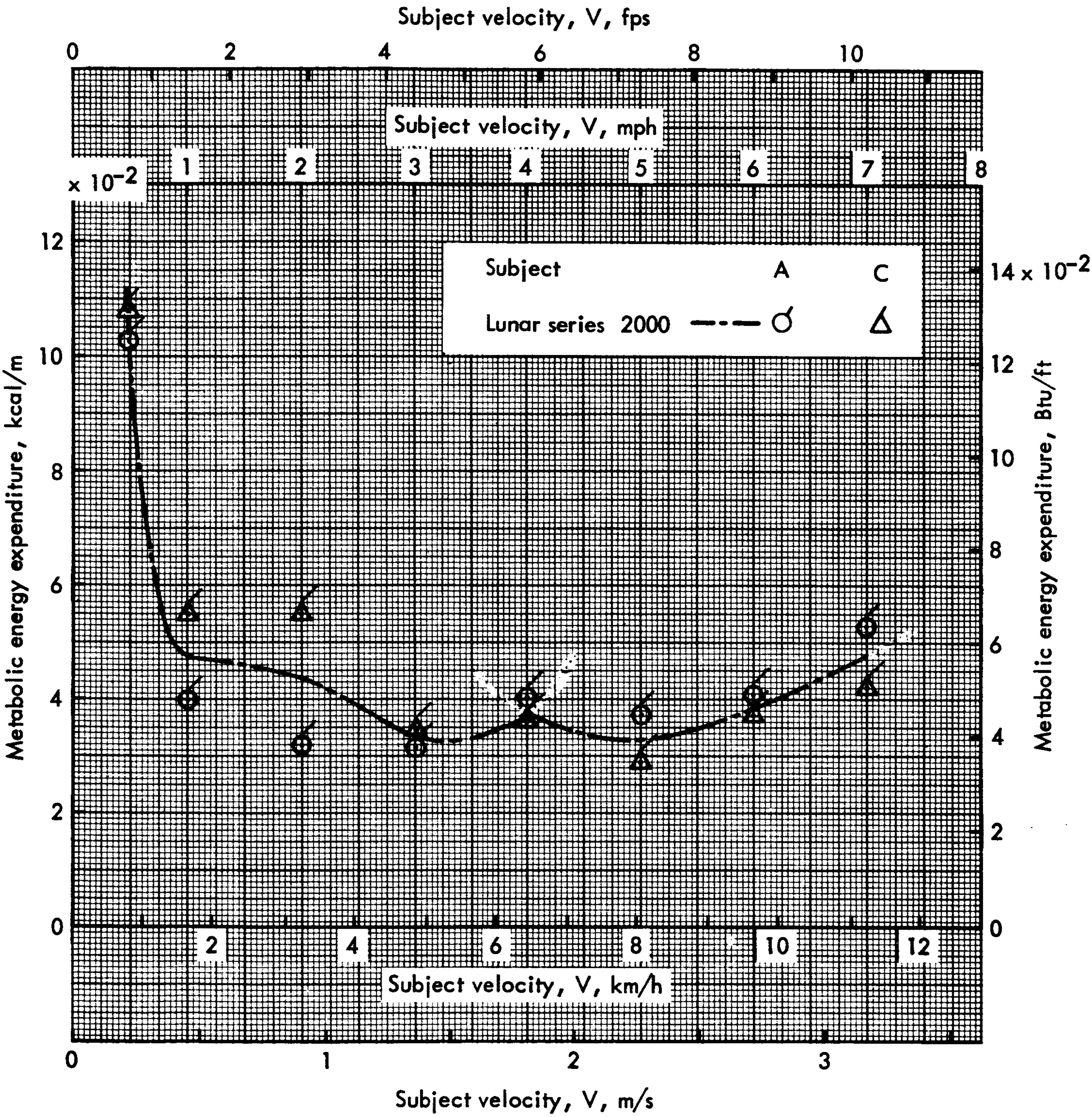


Figure 37. – Average metabolic energy expenditure per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

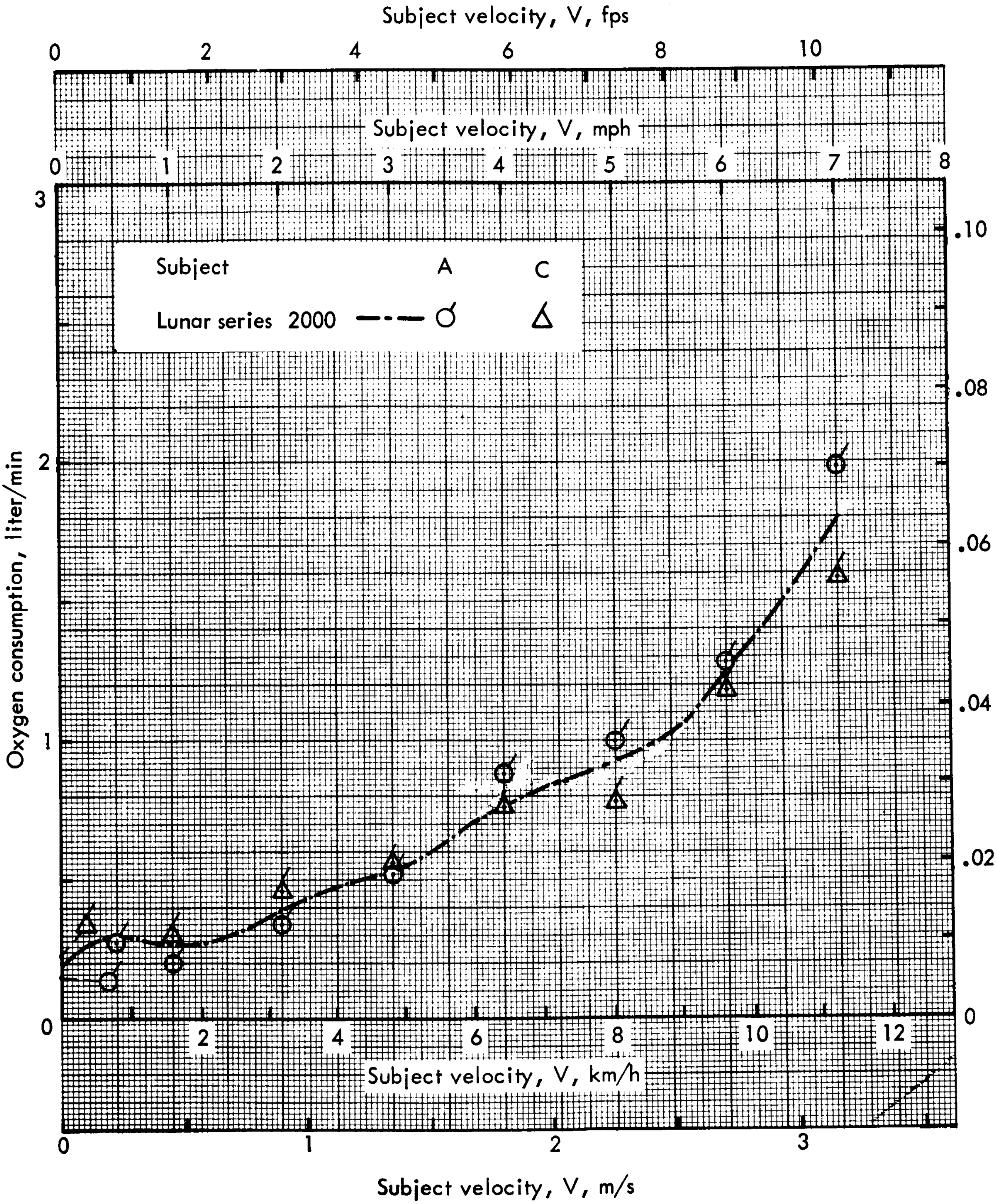


Figure 38. – Average oxygen consumption versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

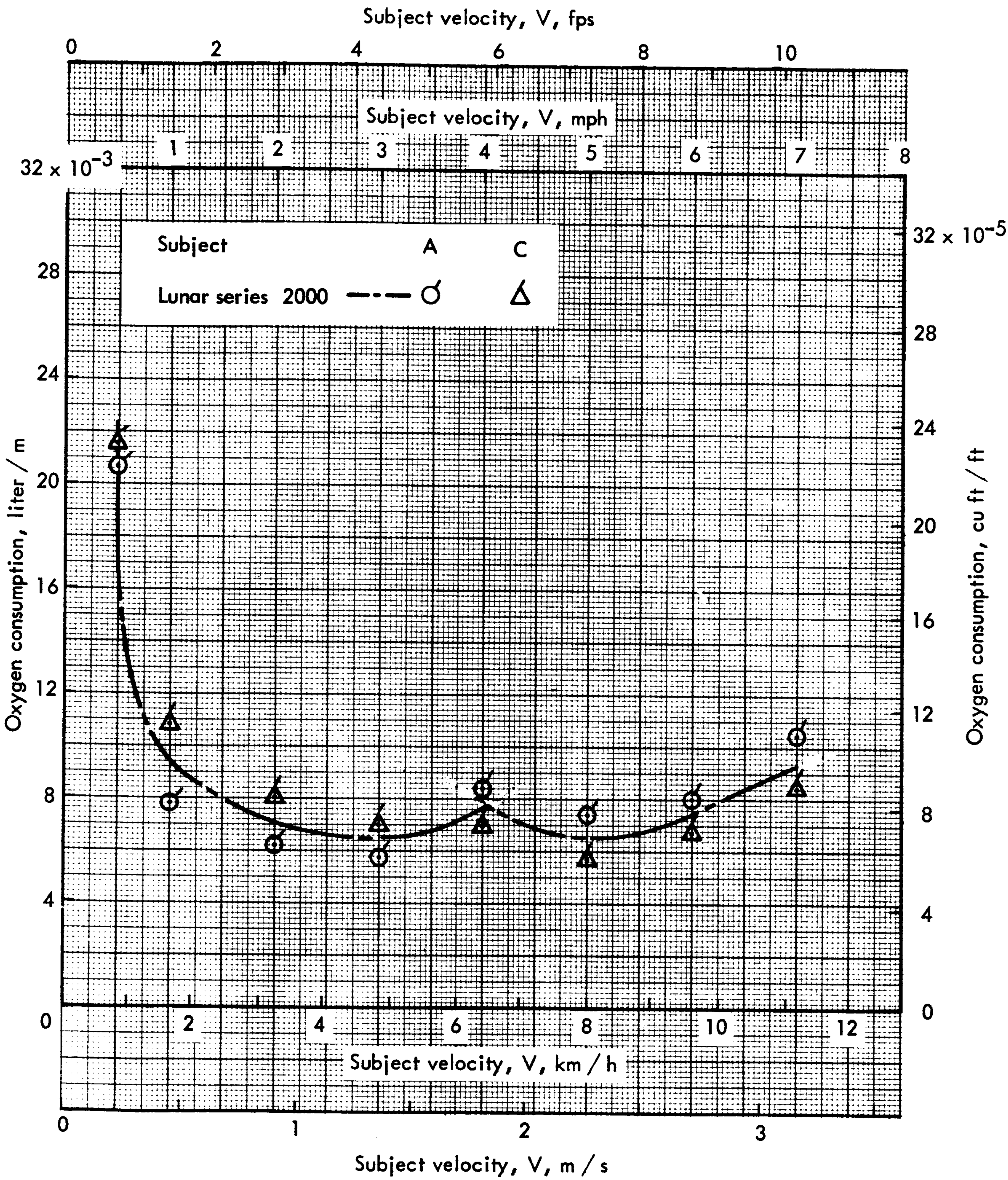


Figure 39. – Average oxygen consumption per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

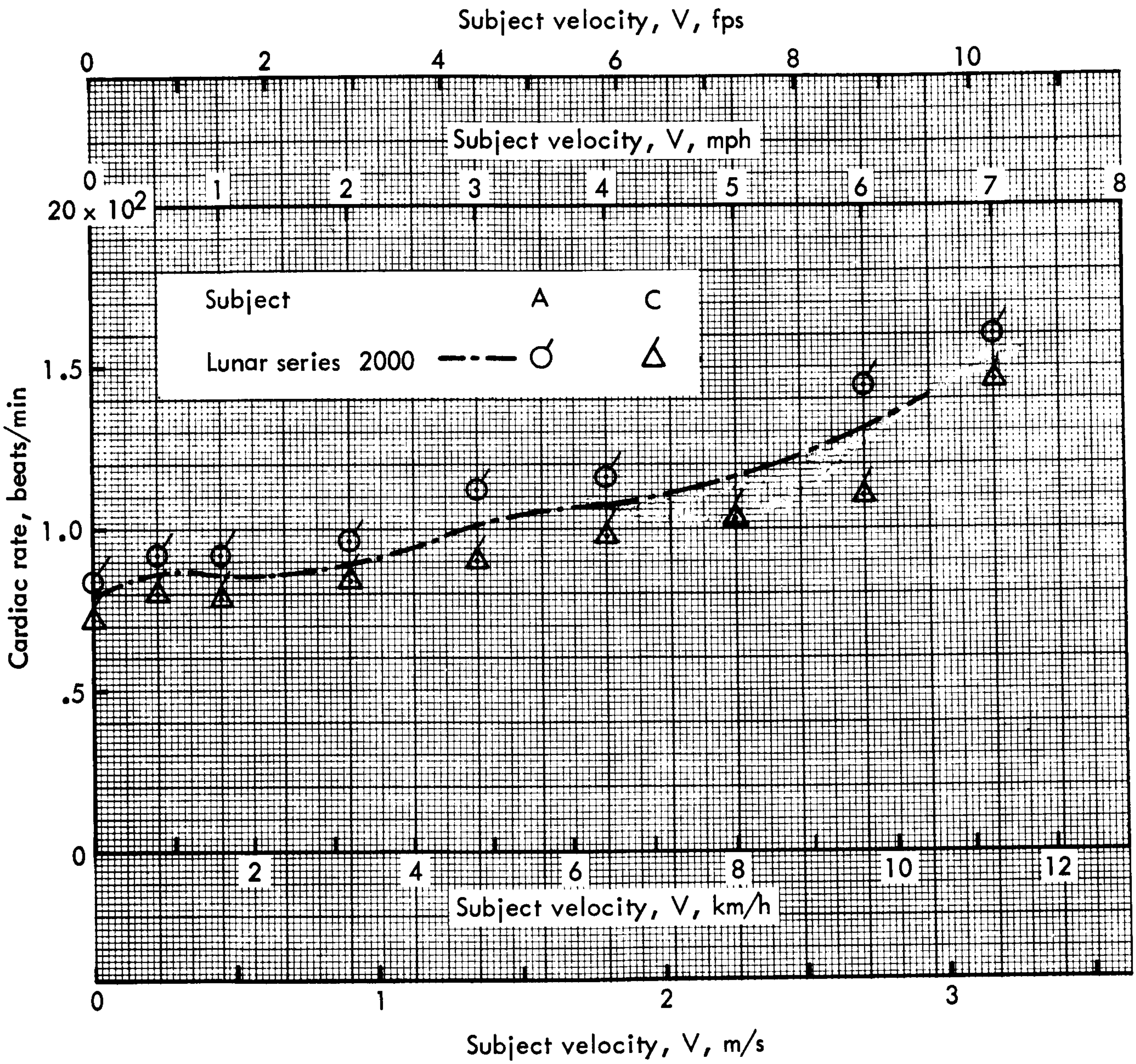


Figure 40. – Average cardiac rate versus subject velocity walking and running horizontally.
Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

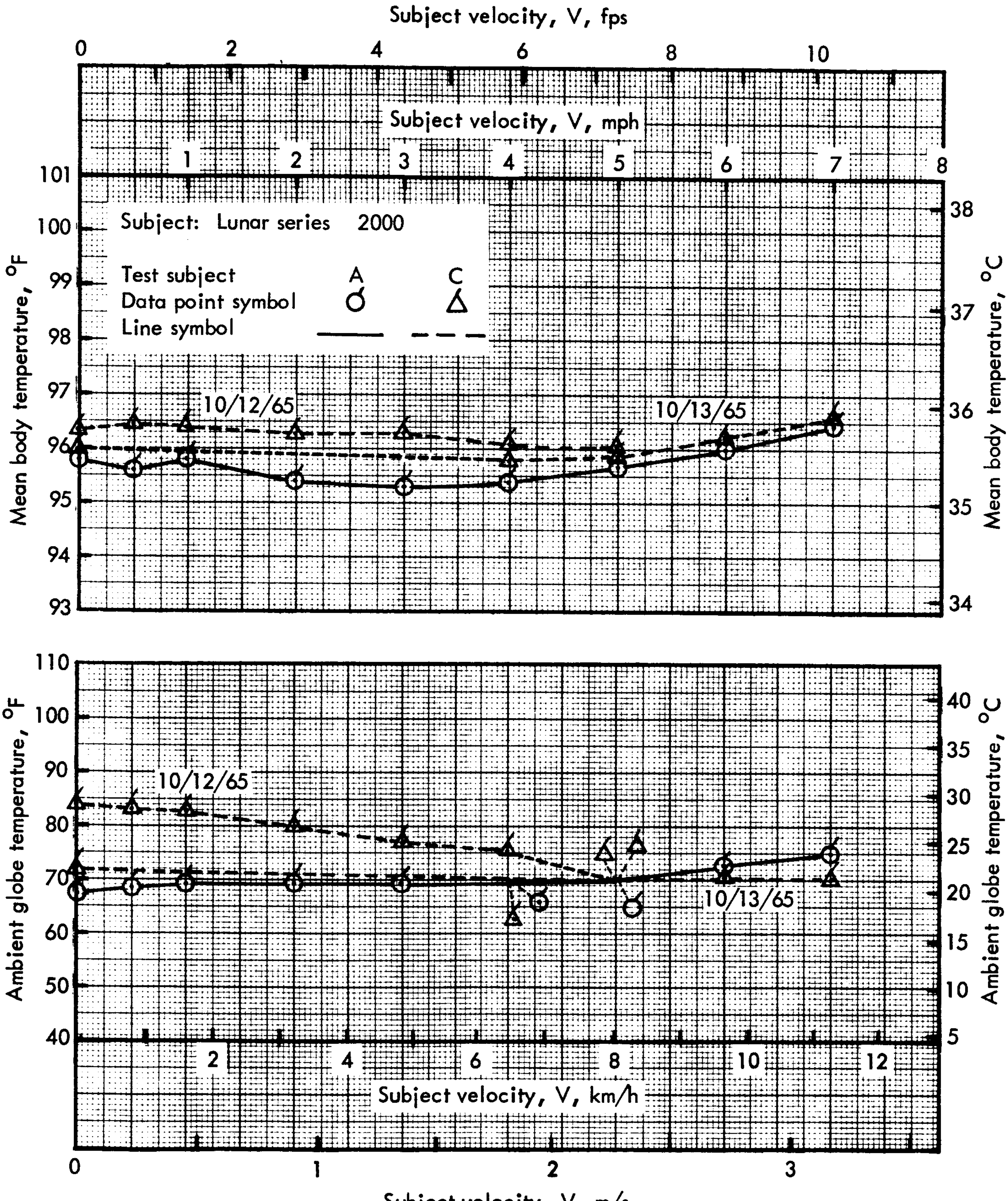


Figure 41. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

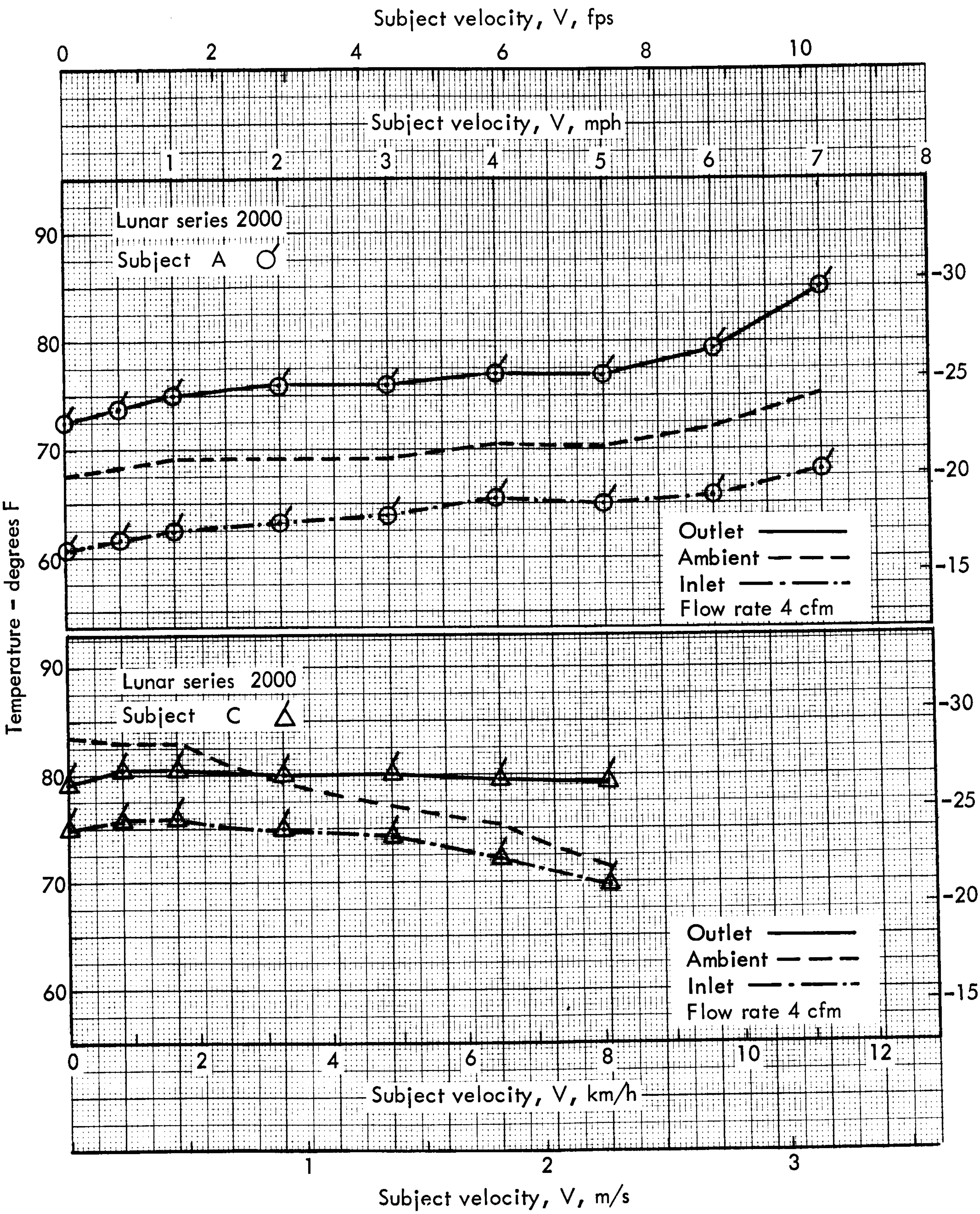


Figure 42. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, walking and running horizontally.

Test conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3000

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	walking and running	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	7		13

Respiration, respiratory rate	Figure 44
respiratory volume expired	Figure 45
Metabolism, metabolic energy expenditure rate	Figure 46 **
metabolic energy expenditure rate per unit length	Figure 47 **
oxygen consumption	Figure 48 **
oxygen consumption per unit length	Figure 49 **
Cardiovascular function, cardiac rate	Figure 50 ***
Body temperature, mean body temperature	Figure 51
Pressure suit environmental data	Figure 52

Comments:

The arrangement for the tests conducted in this series is shown in Figure 43. This figure shows the subject walking on the treadmill with the suit pressurized via the ECS in Instrument Pack II, which he is carrying. In this test, respiration and metabolism are monitored by the respirometer contained in the sealed compartment of Pack II which is pressurized at the suit differential pressure level.

*Respiratory rate for Subject A was obtained only for standing at rest and for Subject B only at rest, .5, 1.0 and 5.0 mph

**Figures 46 thru 49 were modified according to intermediate averages

***Cardiac rate for Subject C at 3 mph was not obtained

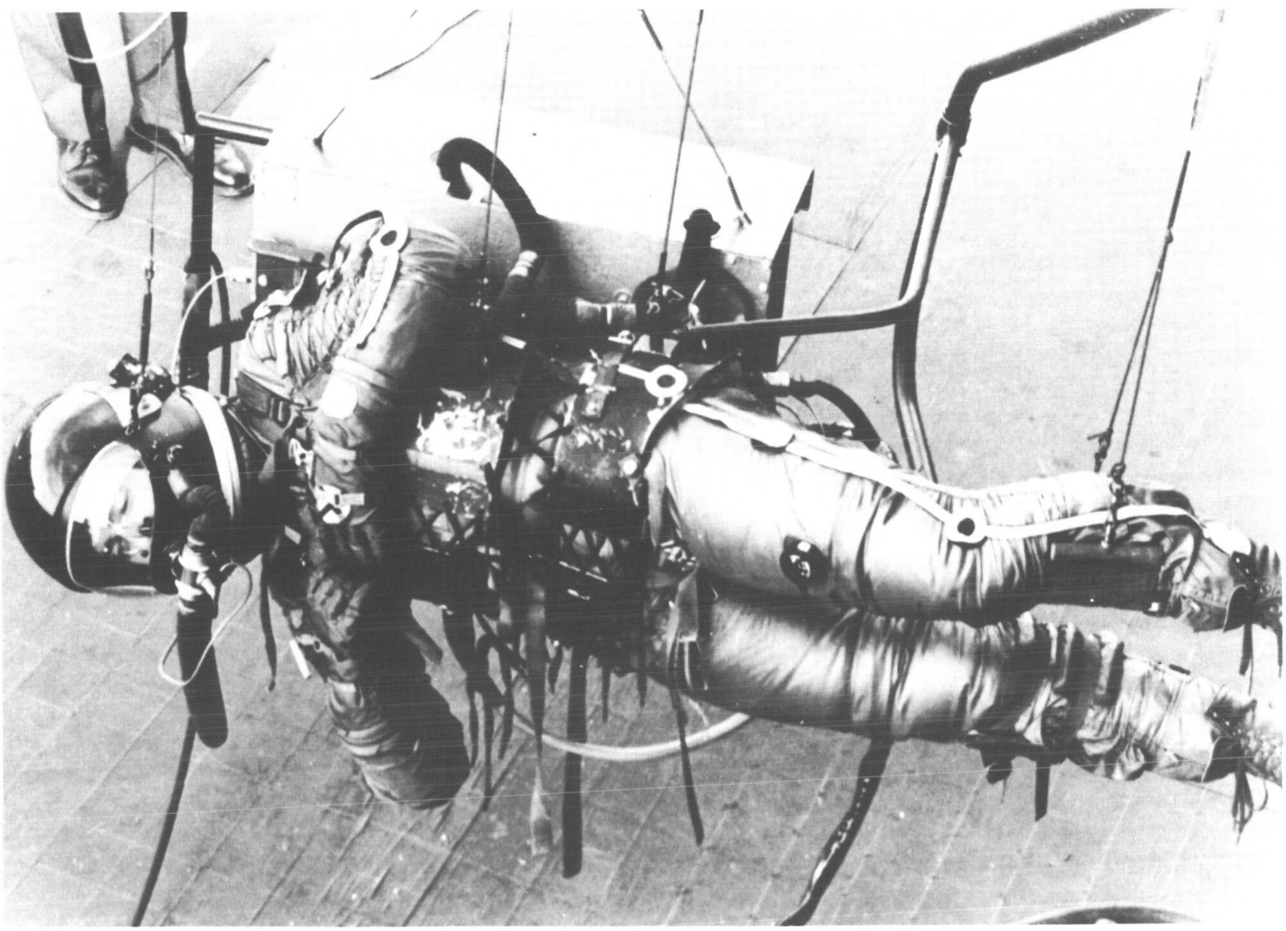


Figure 43. - Illustration of test arrangement for test series 3000

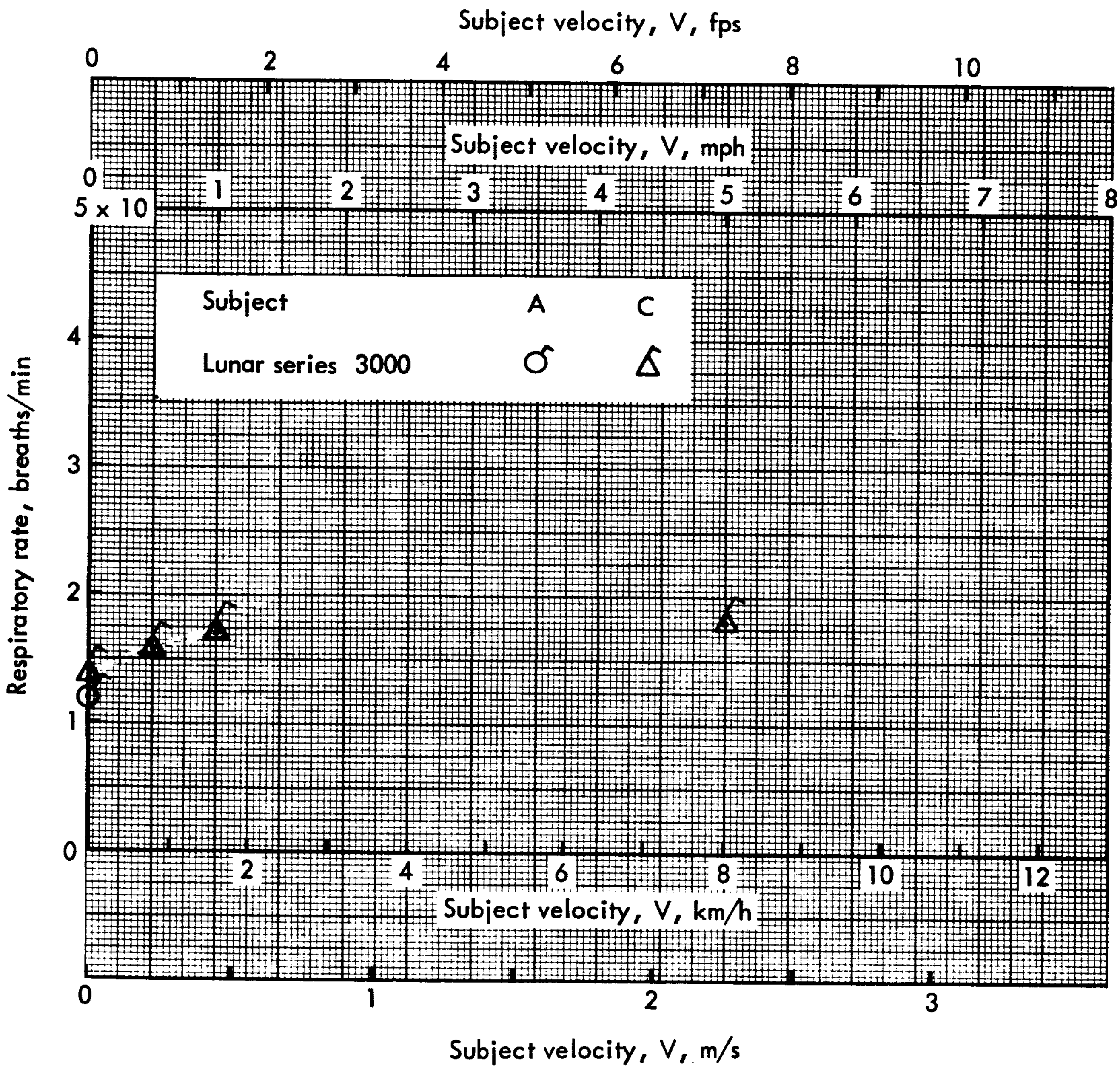


Figure 44. – Respiratory rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

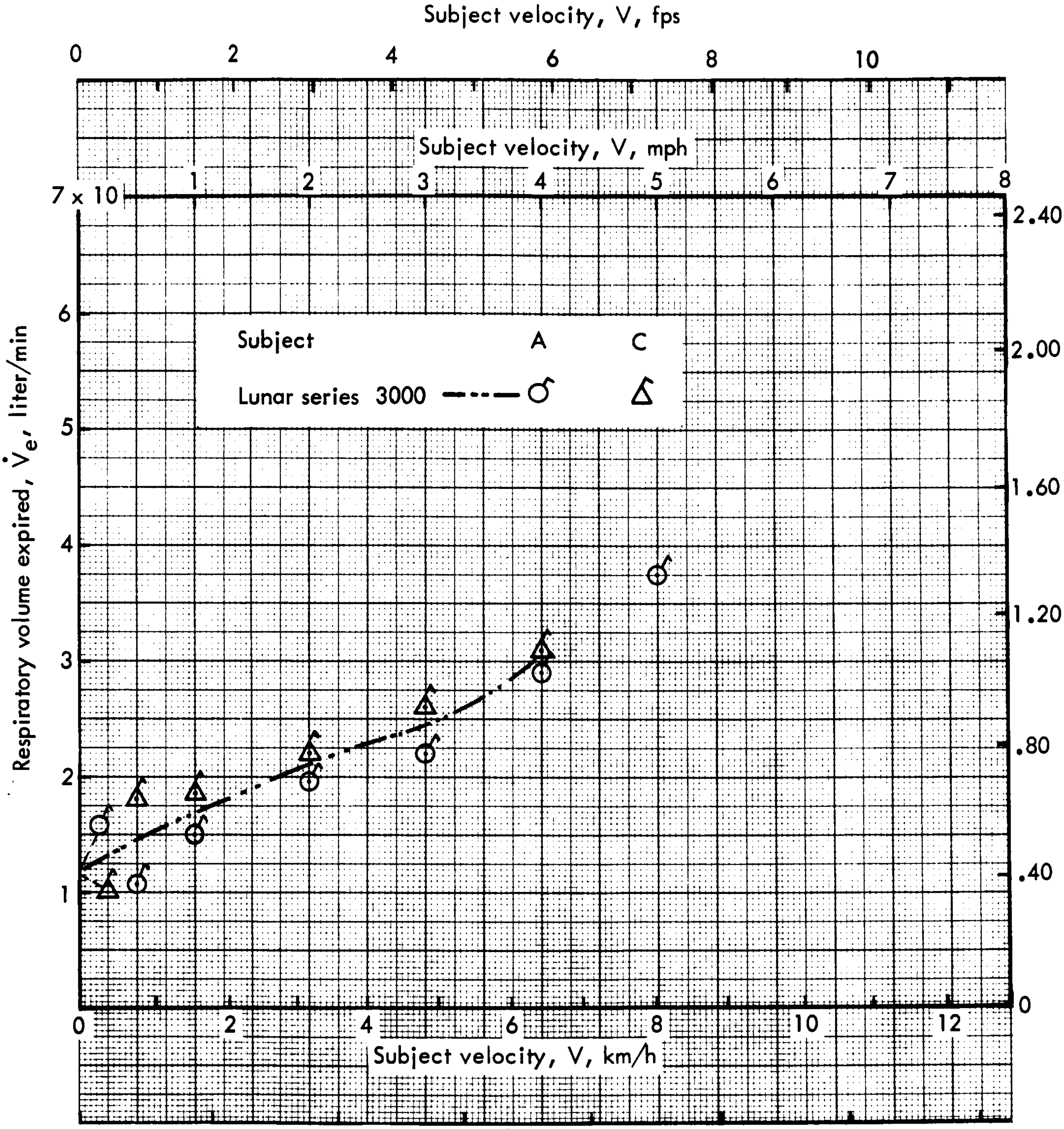


Figure 45. – Average mean respiratory volume versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

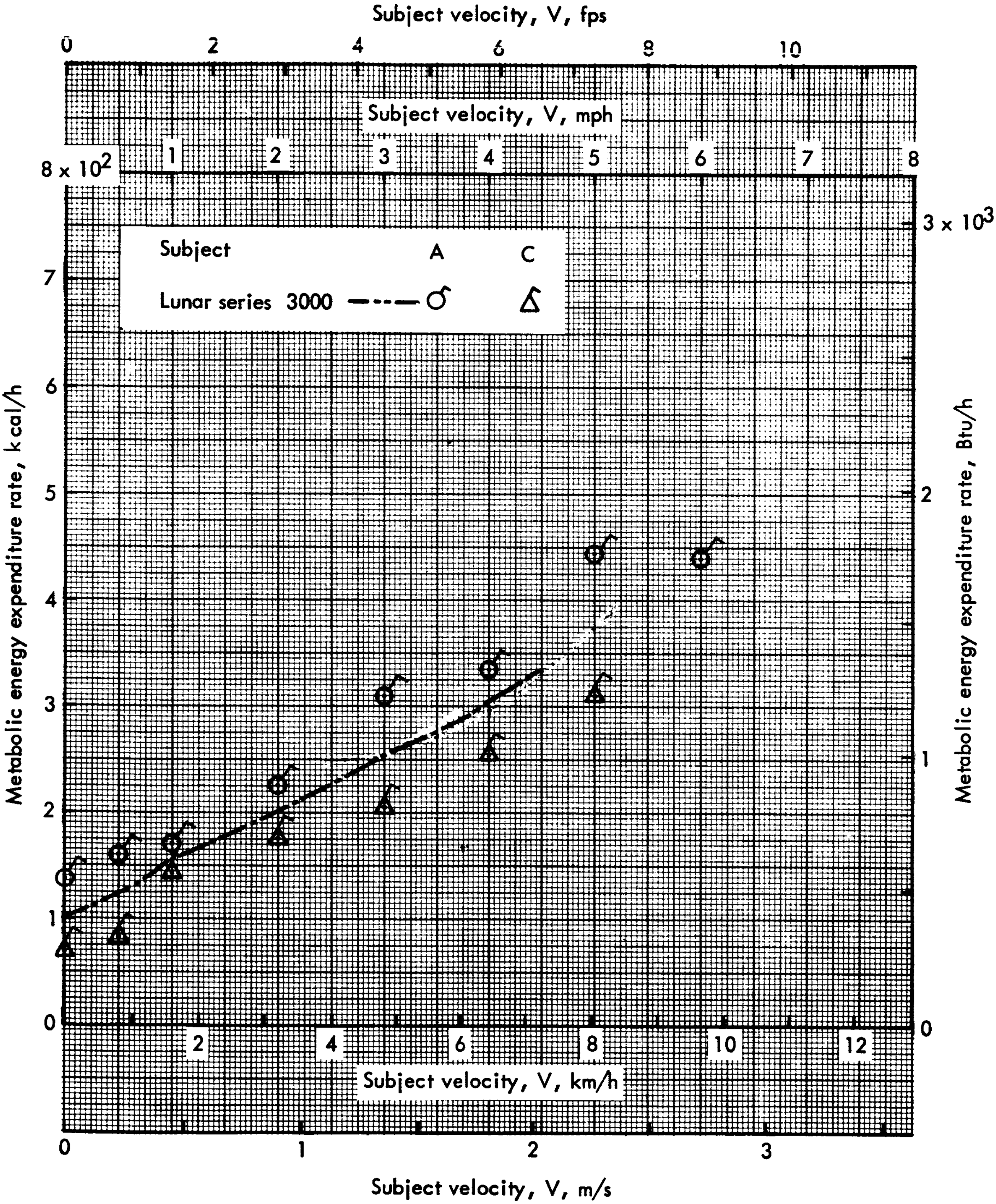


Figure 46. – Average metabolic energy expenditure rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

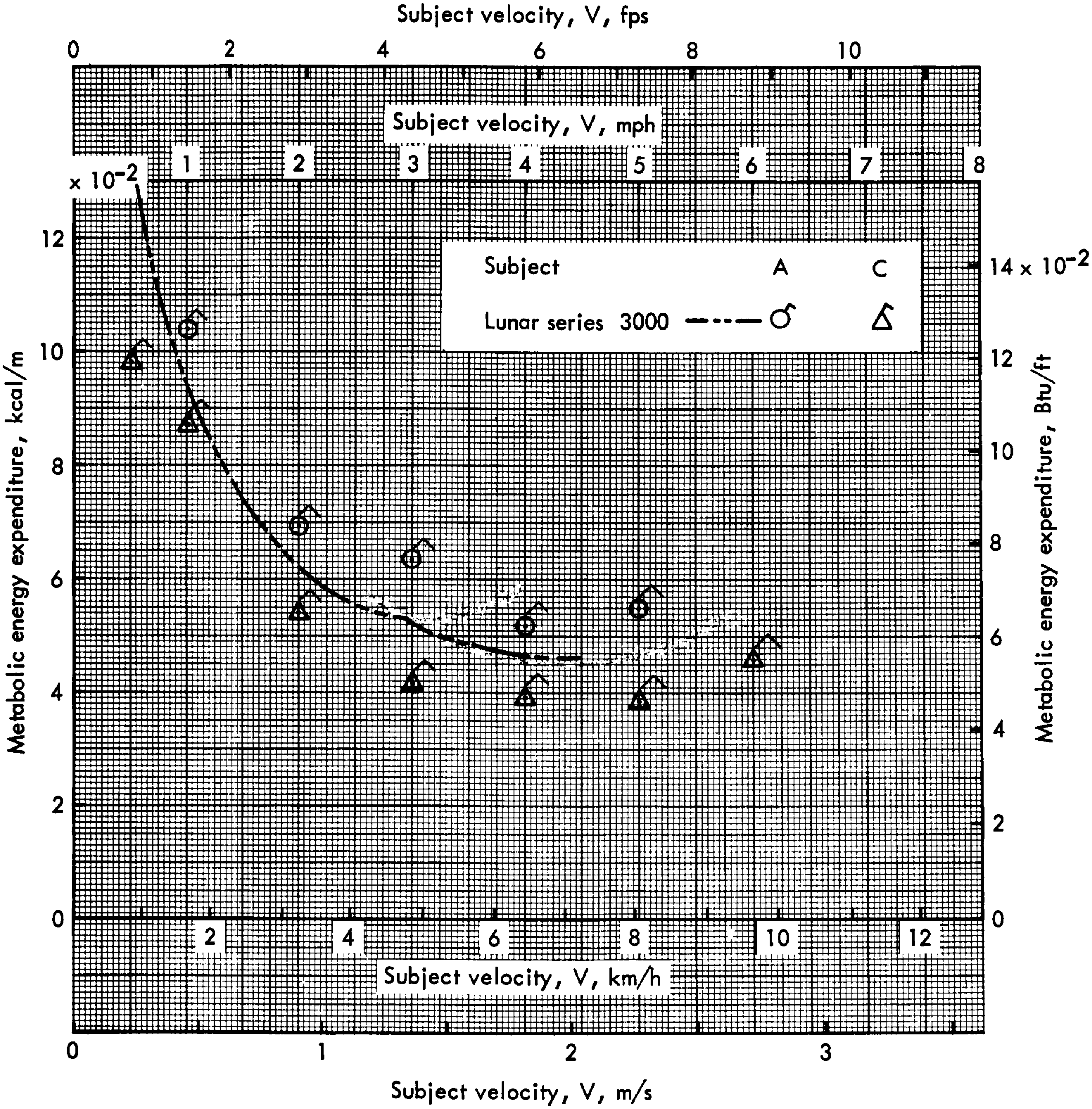


Figure 47. – Average metabolic energy expenditure per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

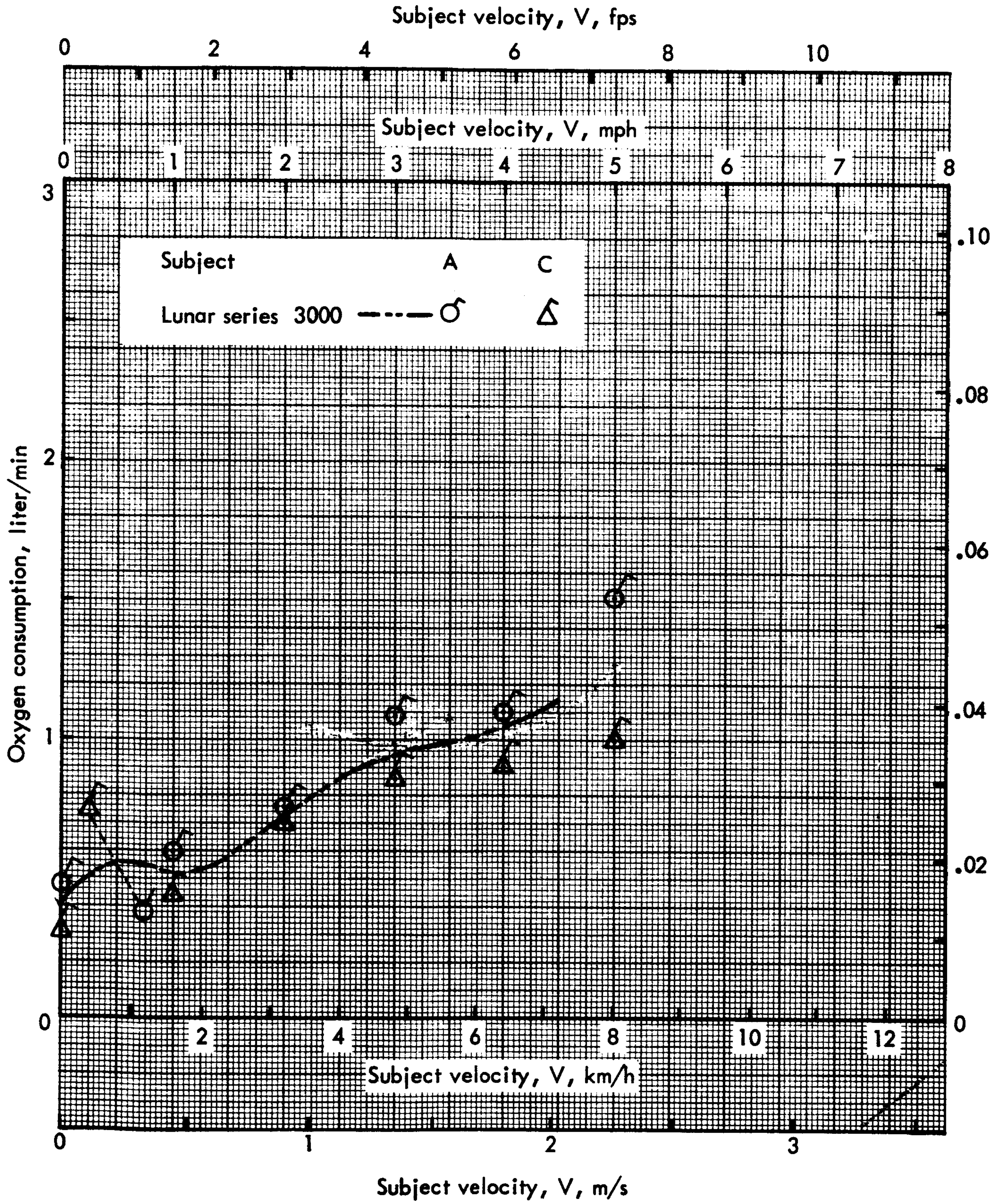


Figure 48. – Average oxygen consumption versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

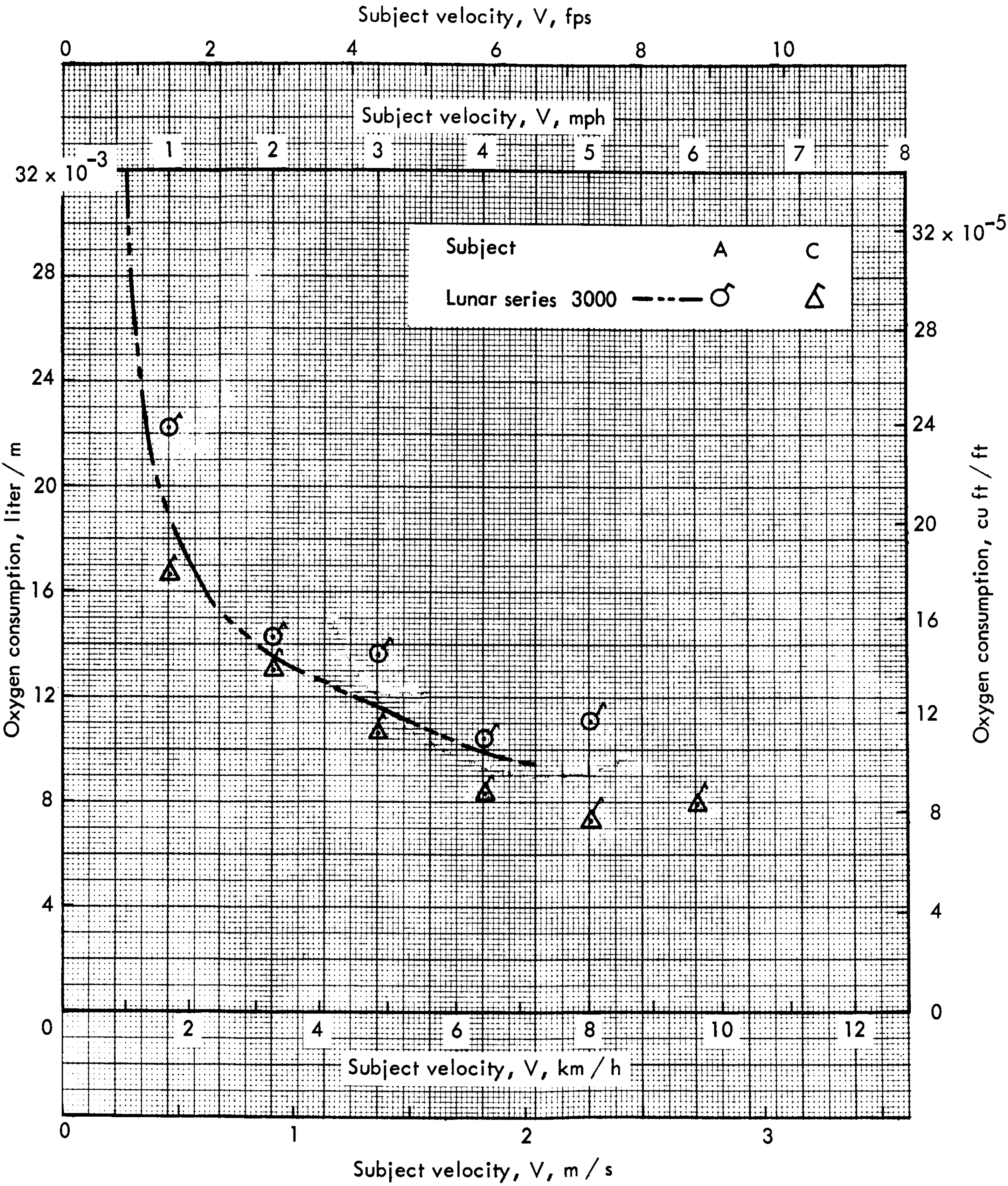


Figure 49. – Average oxygen consumption per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

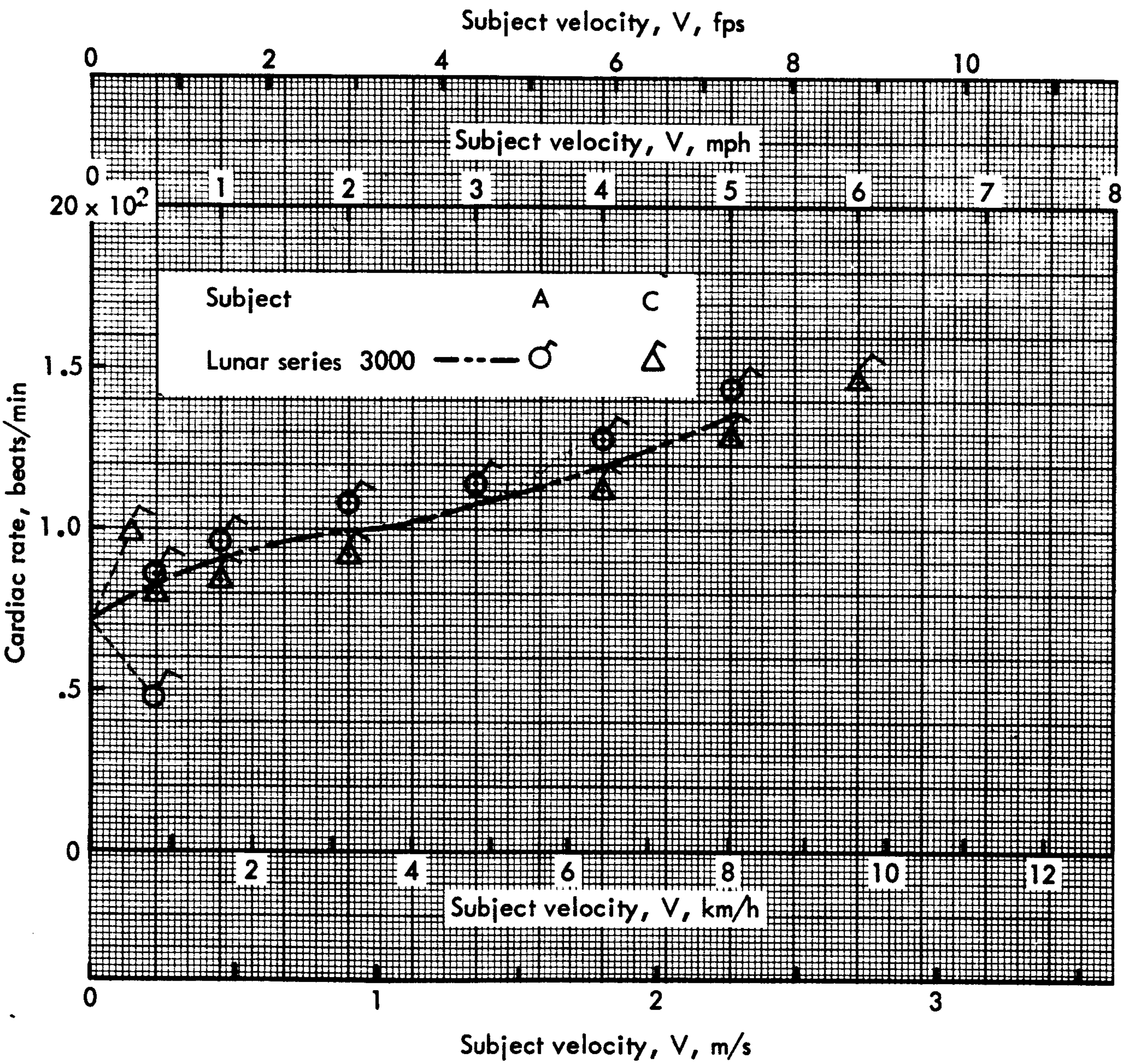


Figure 50. – Average cardiac rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

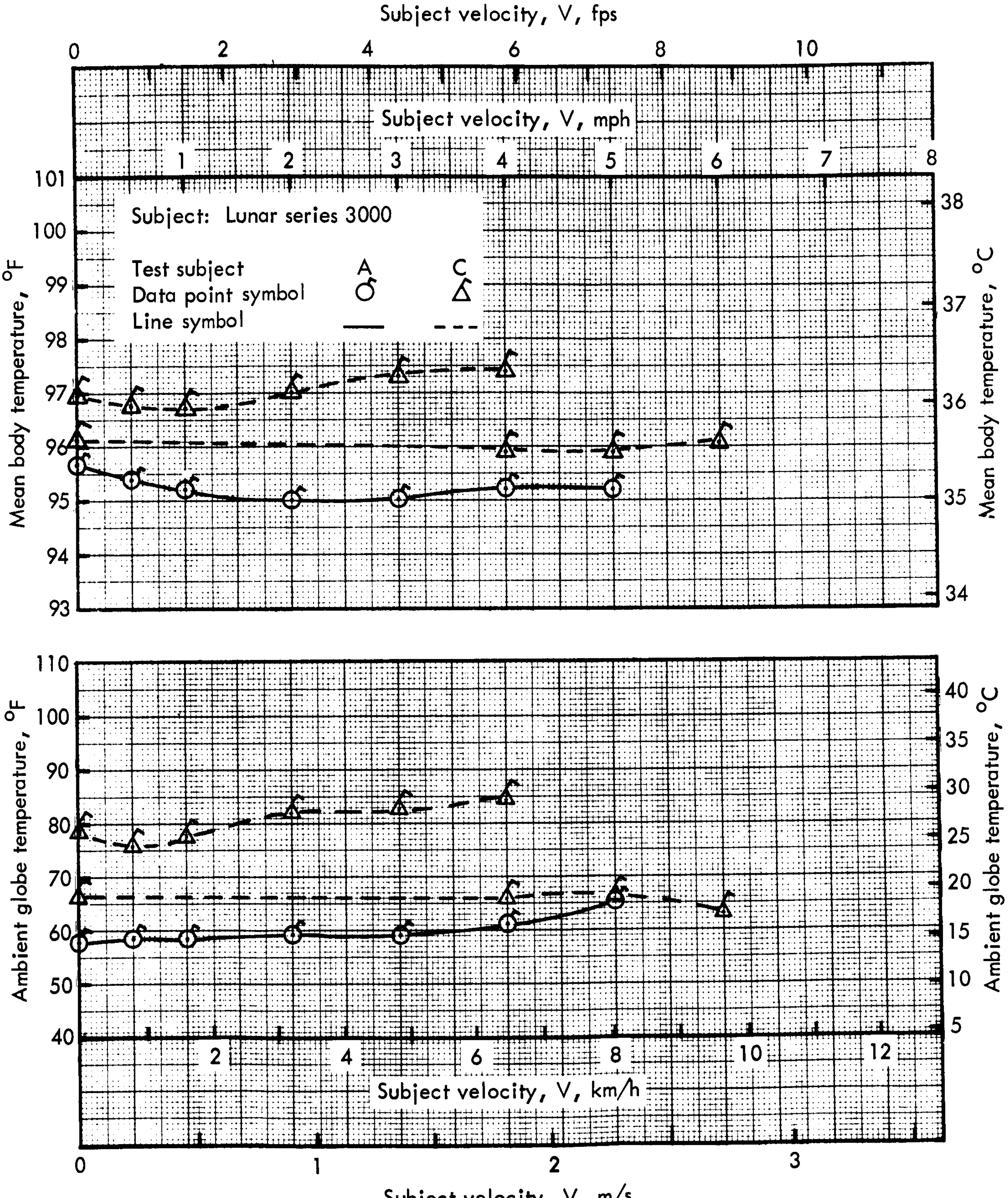


Figure 51. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking and running horizontally. Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

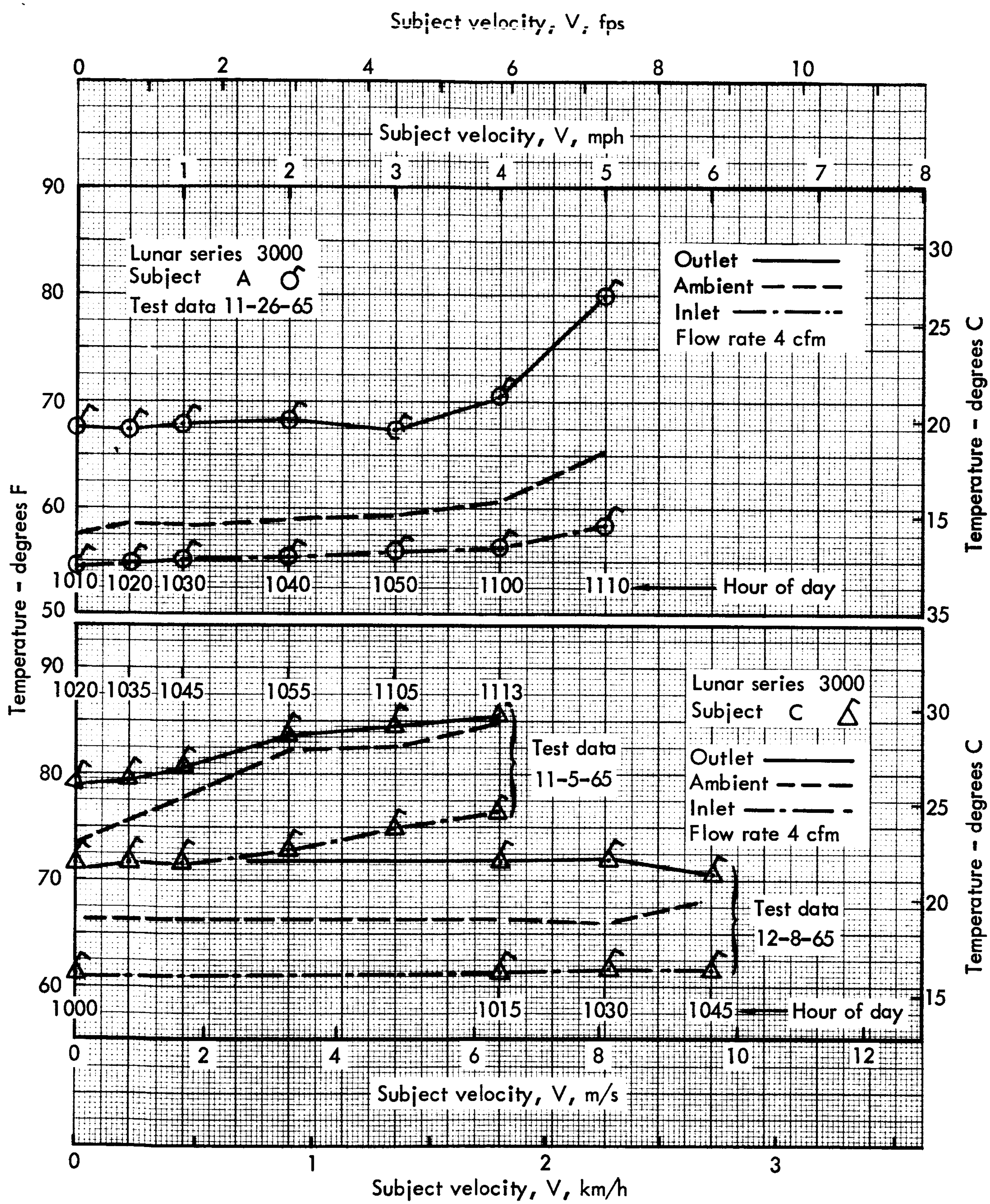


Figure 52. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, walking and running horizontally.

Test conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series 5000

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	none	Instrument Pack II	
Work Activity	walking and running	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	8		8

Respiration,	respiratory rate	Not Obtained
	respiratory volume expired	Figure 54
Metabolism,	metabolic energy expenditure rate	Figure 55
	metabolic energy expenditure rate per unit length	Figure 56 *
	oxygen consumption	Figure 57
	oxygen consumption per unit length	Figure 58*
Cardiovascular function,	cardiac rate	Not Obtained
Body temperature,	mean body temperature	Not Obtained
Pressure suit environmental data		Not Obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 53. The subject in Figure 53 is walking on the inclined treadmill, suspended by the LGS cables and suspension system, Instrument Pack I, by which respiration and metabolism are monitored, is independently supported in front of the subject.

*Figures 56, and 58 were modified according to intermediate averages

Figure 53. - Illustration of test arrangement for test series 5000

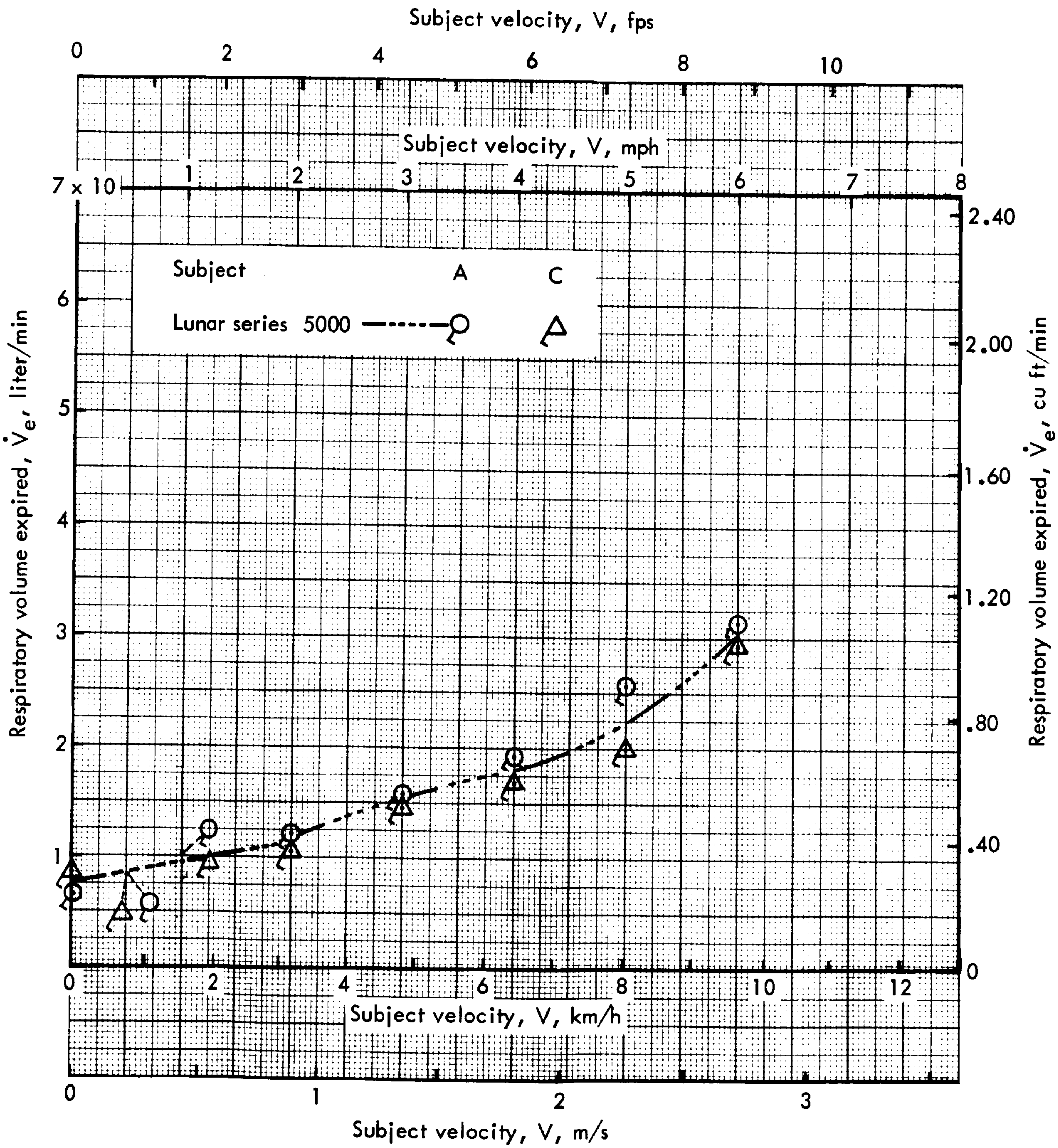


Figure 54. – Average mean respiratory volume versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, no pack

Test Conditions: 1/6 g, shirtsleeve, susp. gear, no pack

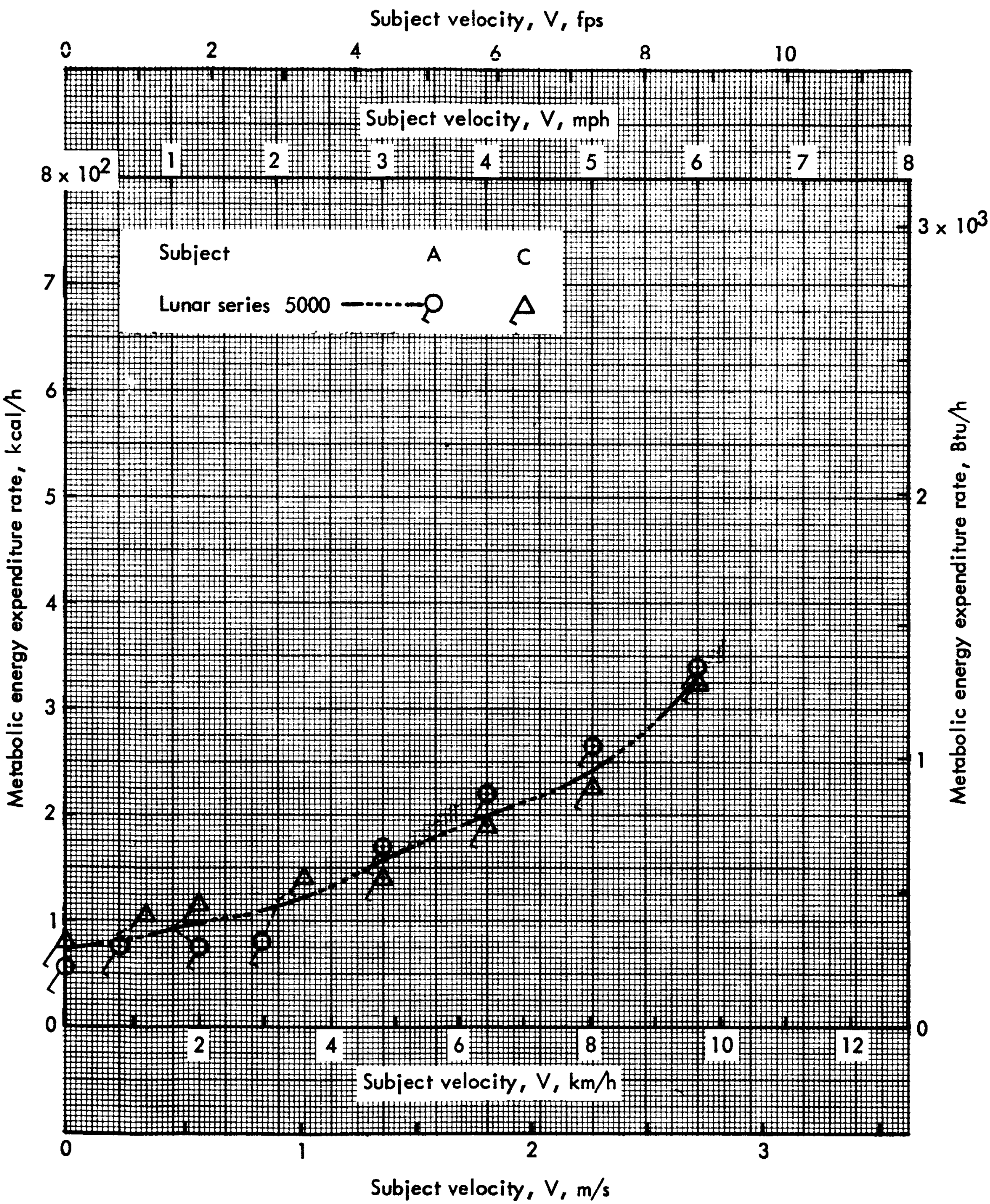


Figure 55. – Average metabolic energy expenditure rate versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, no pack

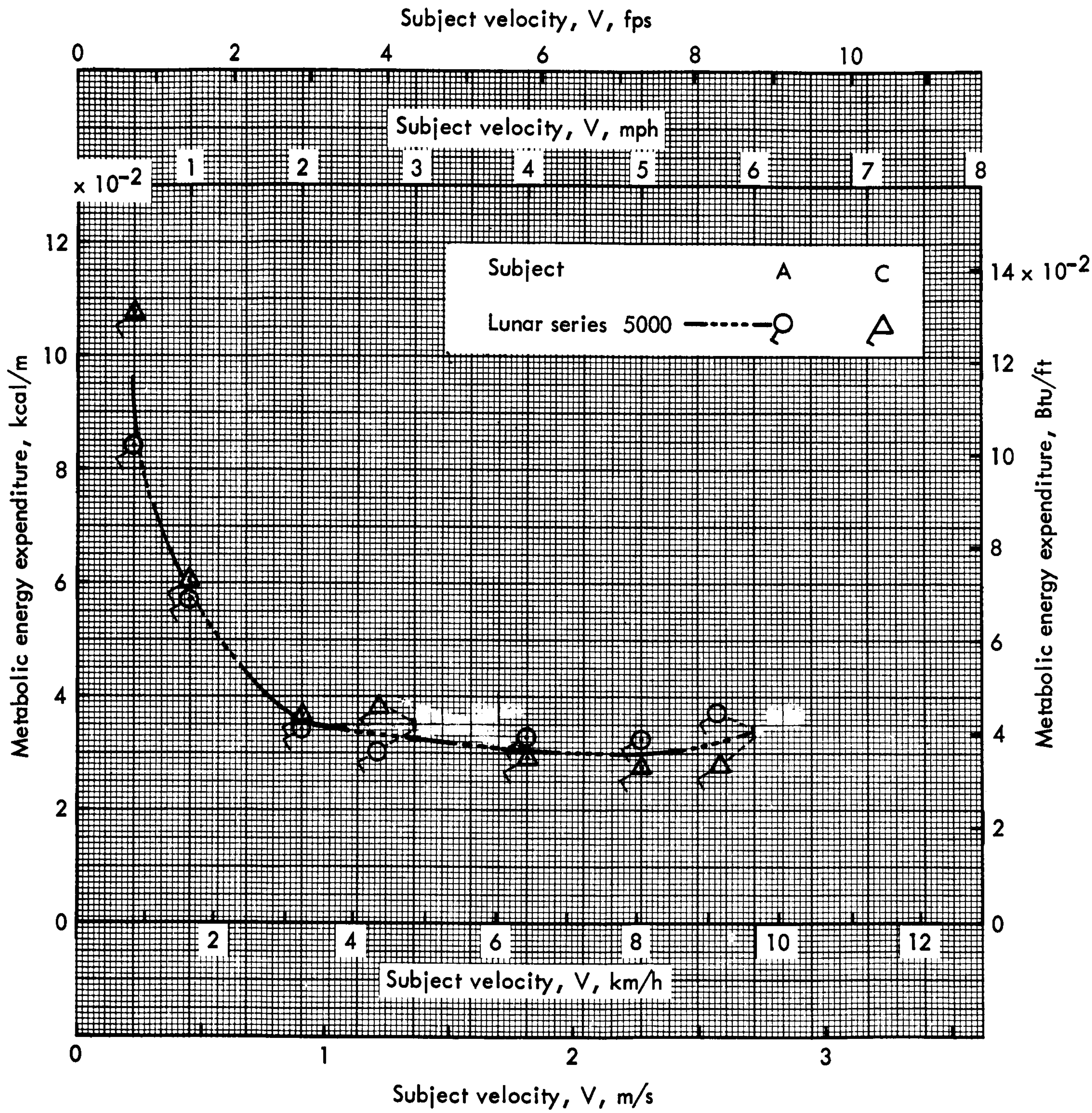


Figure 56. – Average metabolic energy expenditure per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, no pack

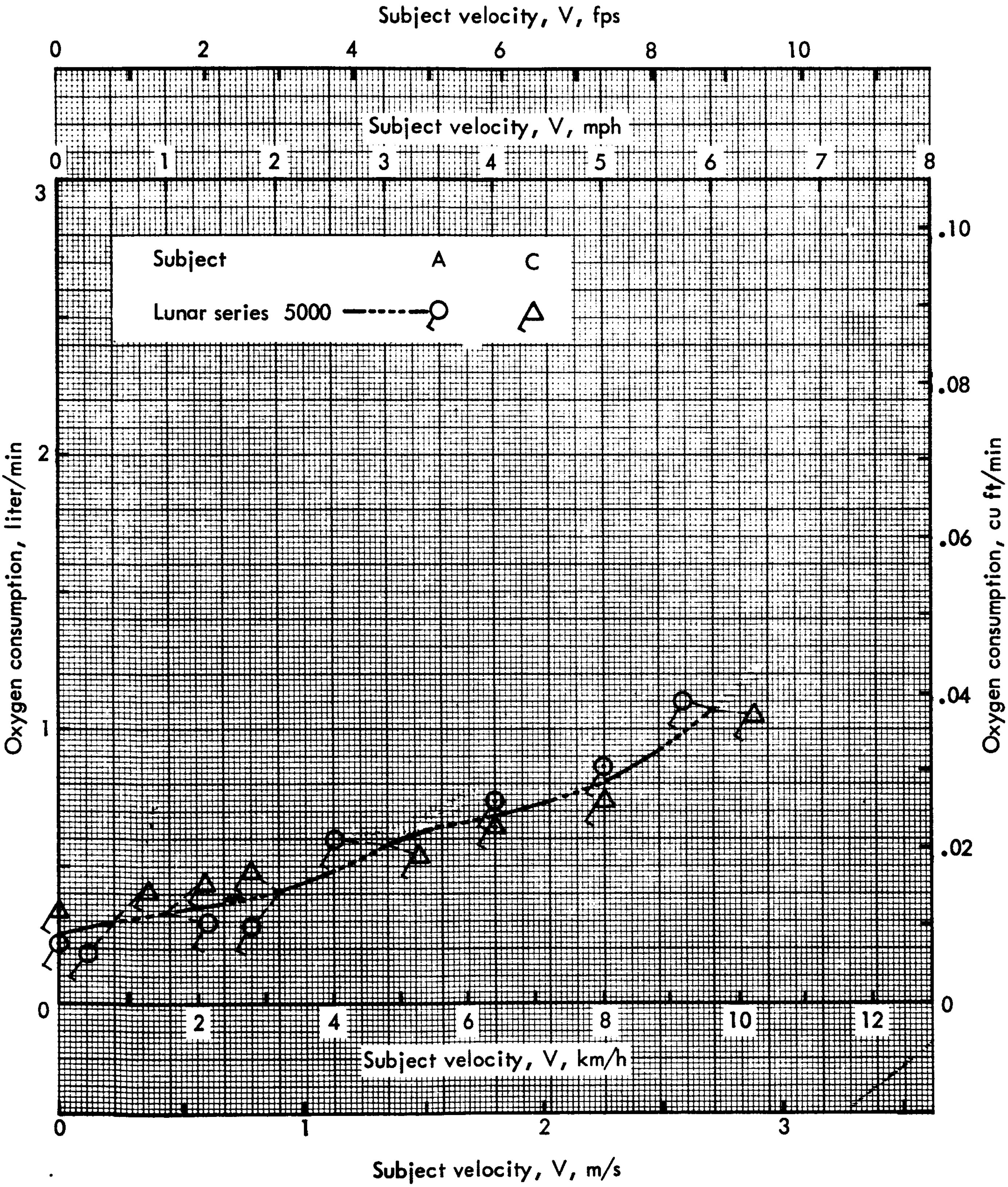


Figure 57. – Average oxygen consumption versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, no pack

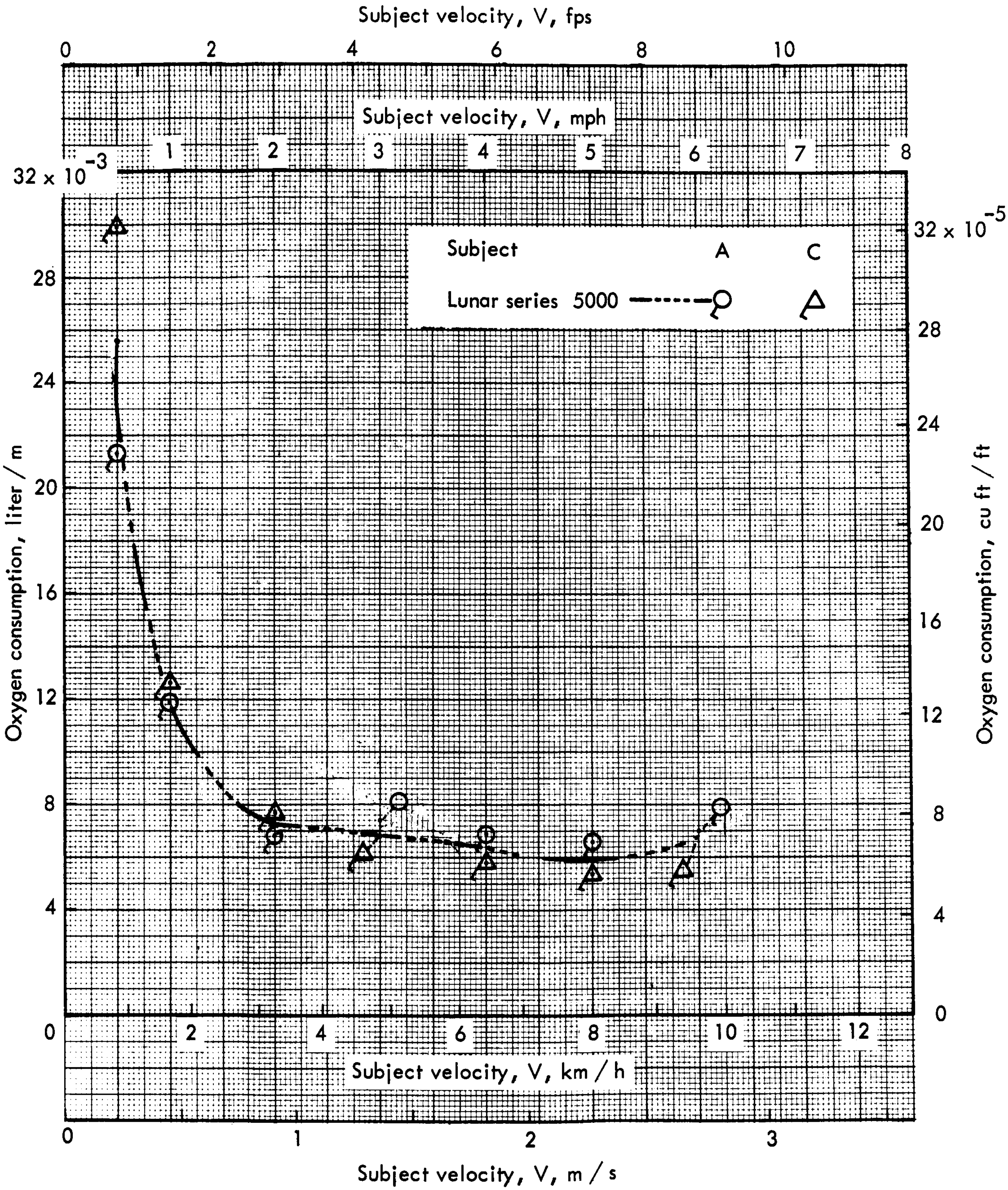


Figure 58. – Average oxygen consumption per unit length versus subject velocity walking and running horizontally.

Test conditions: 1/6 g, shirtsleeve, susp. gear, no pack

Test Series 5500

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	none	Instrument Pack II	
Work Activity	walking	Work Variable	horizontally
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x*

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	27	6	12

Respiration,	respiratory rate	Figure 60
	respiratory volume expired	Figure 61
Metabolism.	metabolic energy expenditure rate	Figure 62
	metabolic energy expenditure rate per unit length	Not Obtained
	oxygen consumption	Figure 63
	oxygen consumption per unit length	Not Obtained
Cardiovascular function,	cardiac rate	Figure 64
Body temperature,	mean body temperature	Not Obtained
Pressure suit environmental data		Not Obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 59. Figure 59 shows a subject on the treadmill, with Instrument Pack I at one side; with the Mueller-Franz meter in use to measure respiration and metabolic rate.

*One g treadmill speed limited to 4 mph.

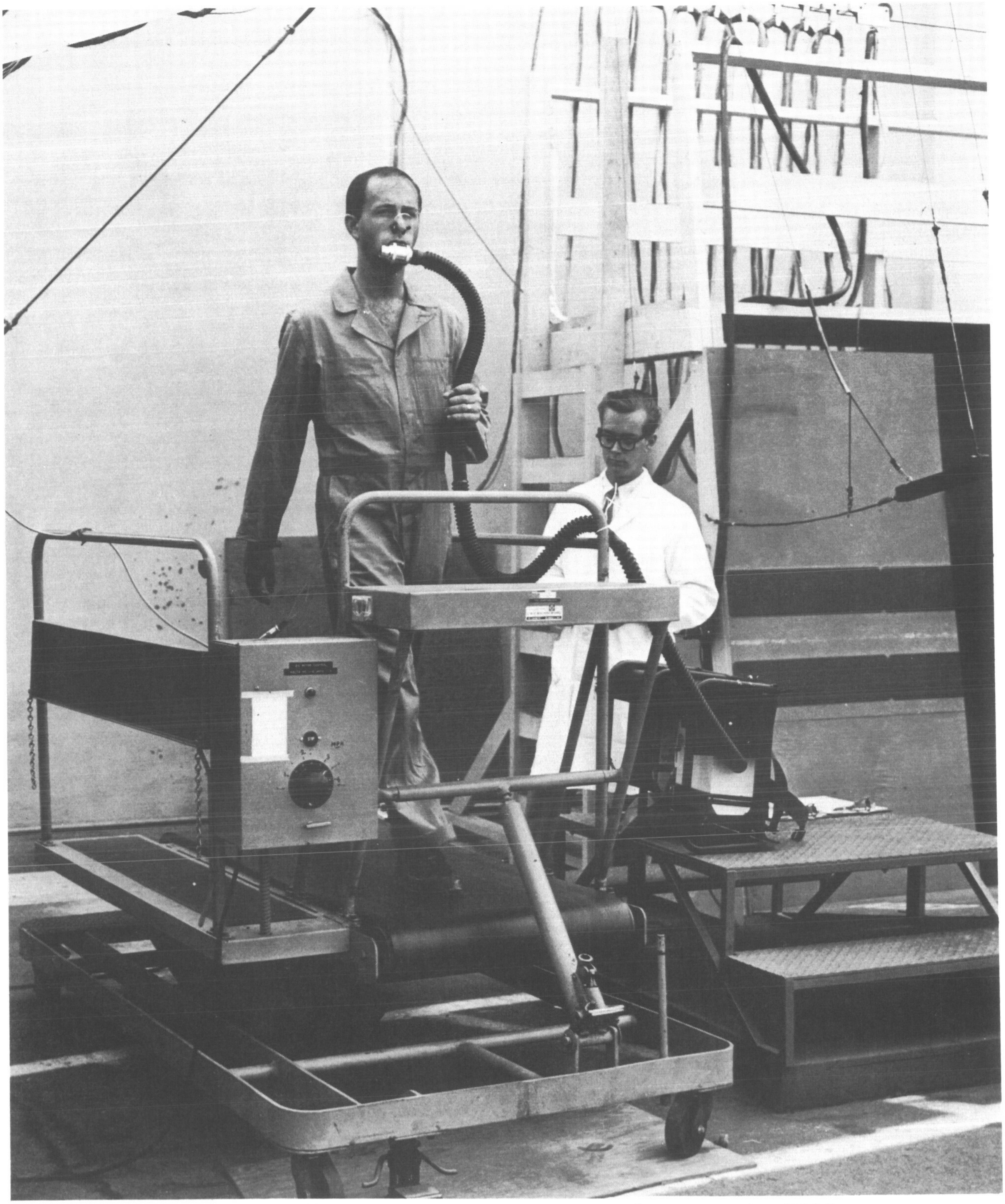


Figure 59. - Illustration of test arrangement for test series 5500

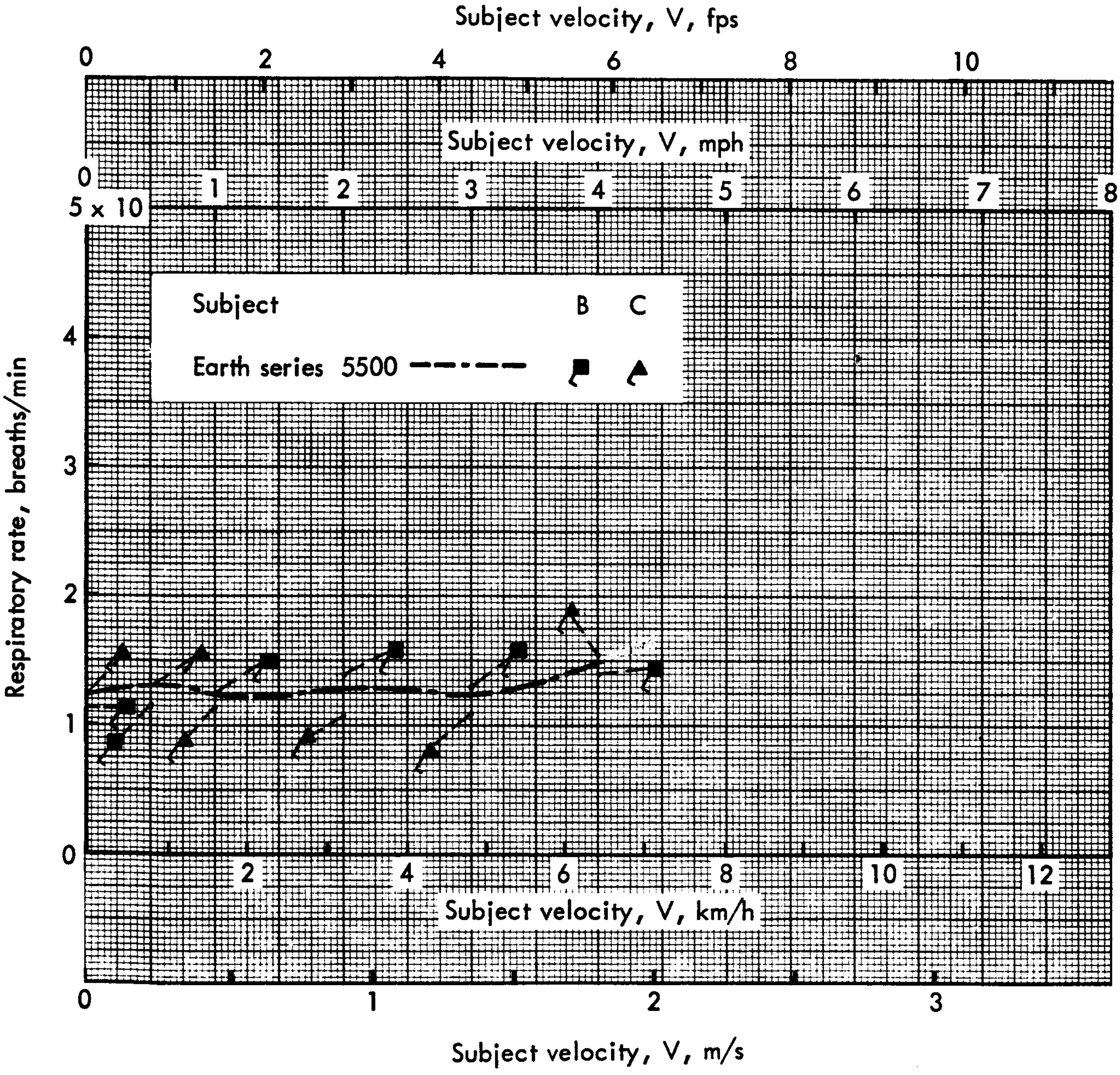


Figure 60. – Average respiratory rate versus subject velocity walking horizontally. Test conditions: 1 g, shirtsleeve, no susp. gear, no pack

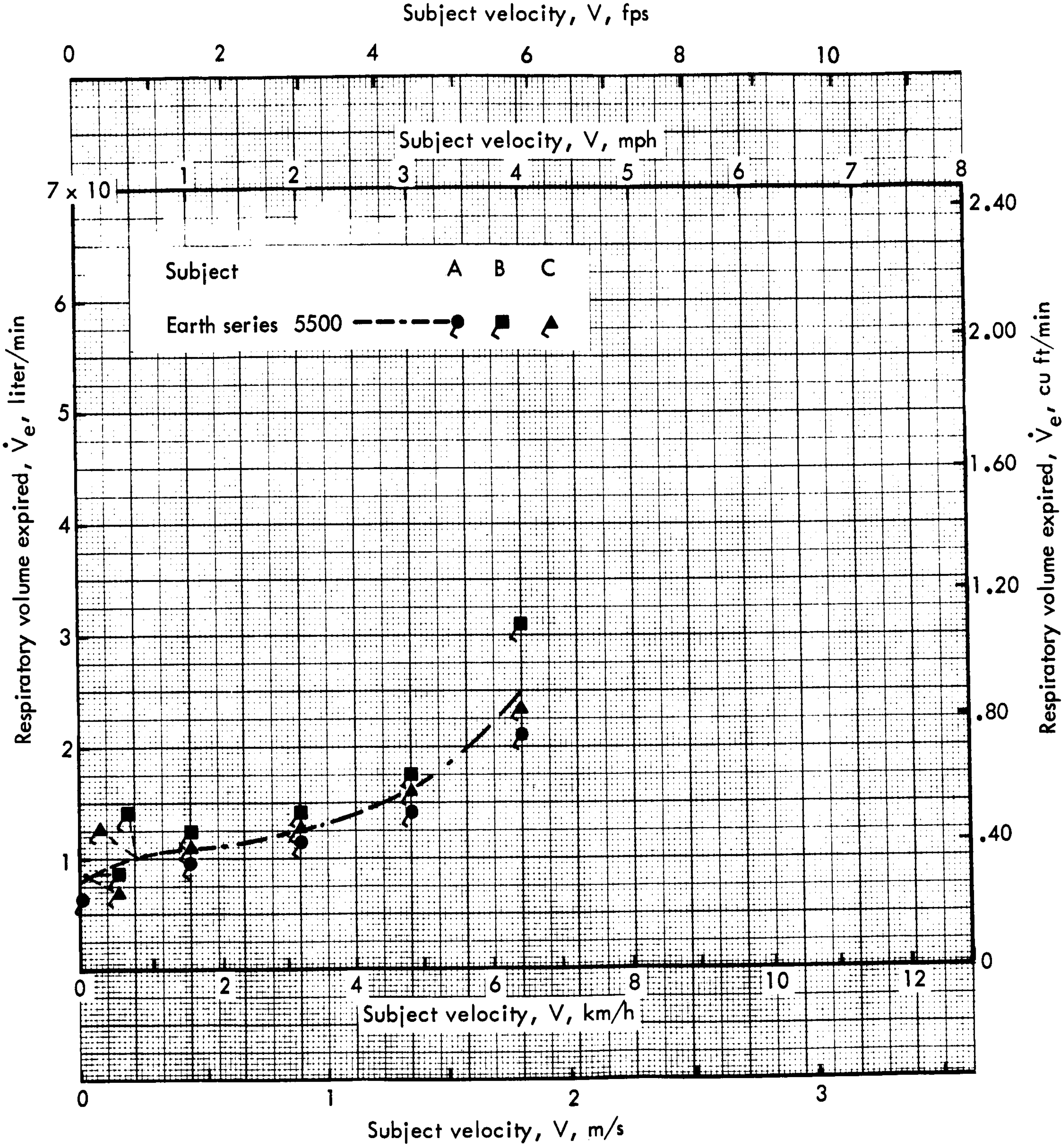


Figure 61. – Average mean respiratory volume versus subject velocity walking horizontally.

Test conditions: 1 g, shirtsleeve, no susp. gear, no pack

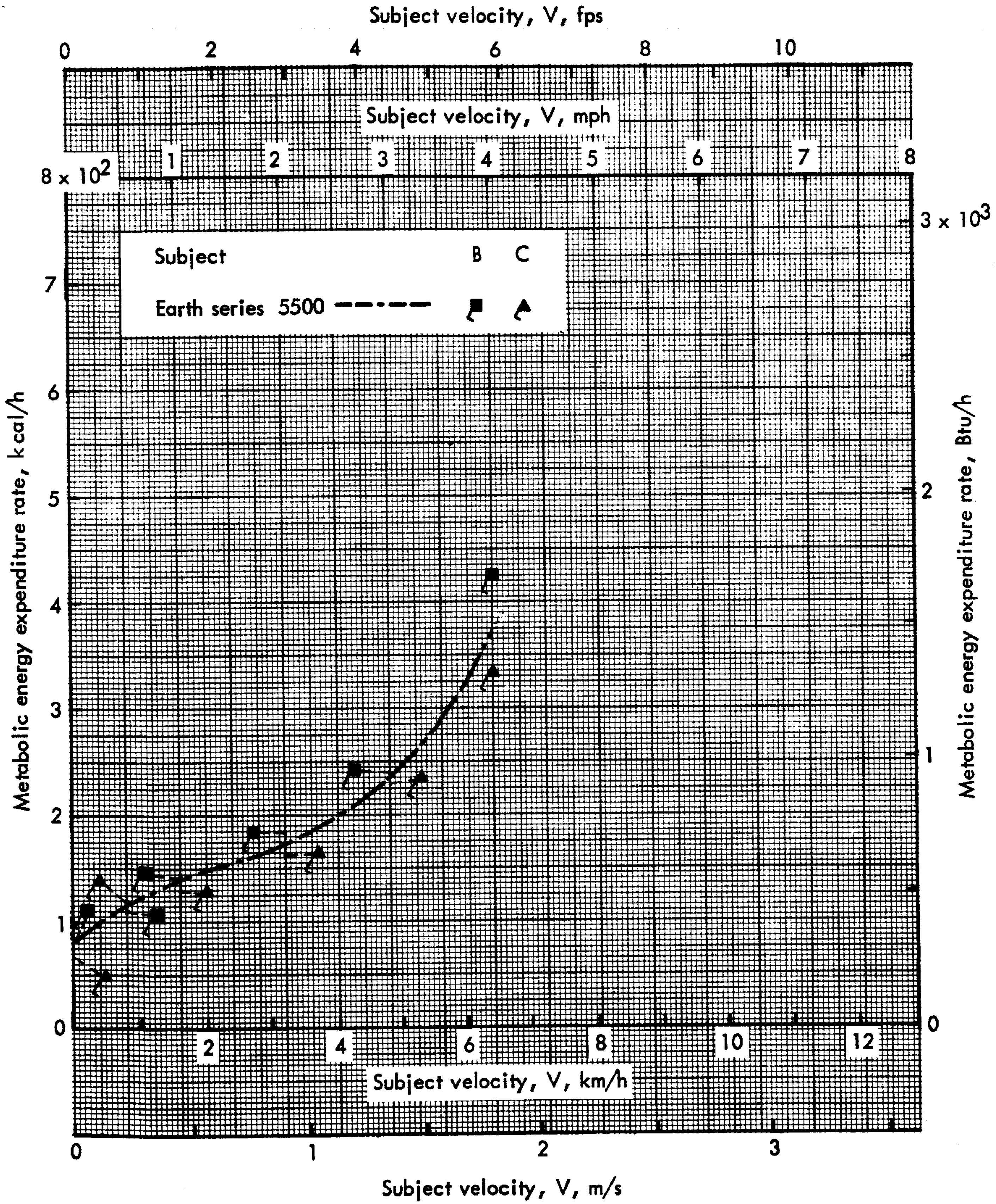


Figure 62. – Average metabolic energy expenditure rate versus subject velocity walking horizontally.

Test conditions: 1 g, shirtsleeve, no susp. gear, no pack

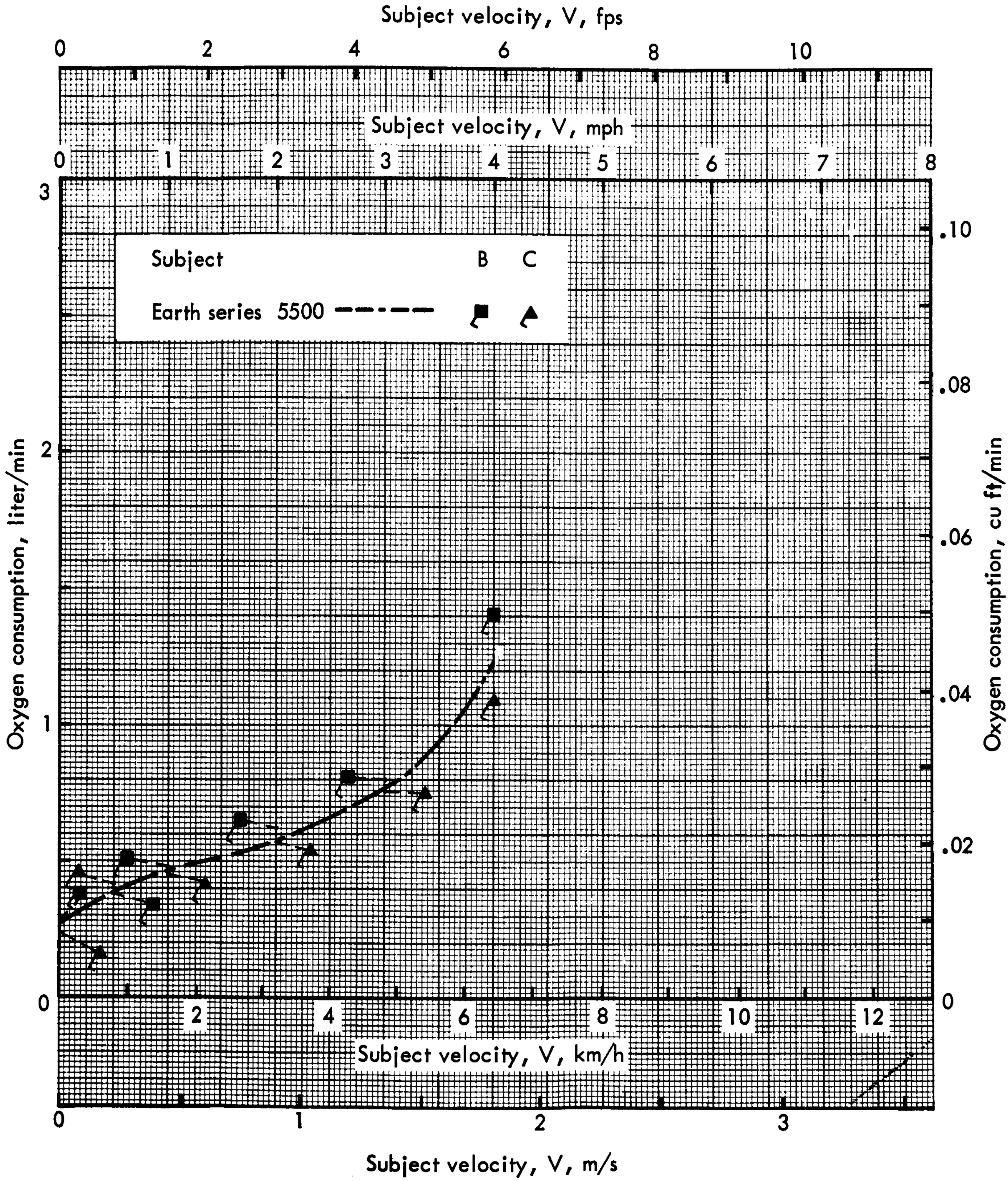


Figure 63. – Average oxygen consumption versus subject velocity walking horizontally.
Test conditions: 1 g, shirtsleeve, no susp. gear, no pack

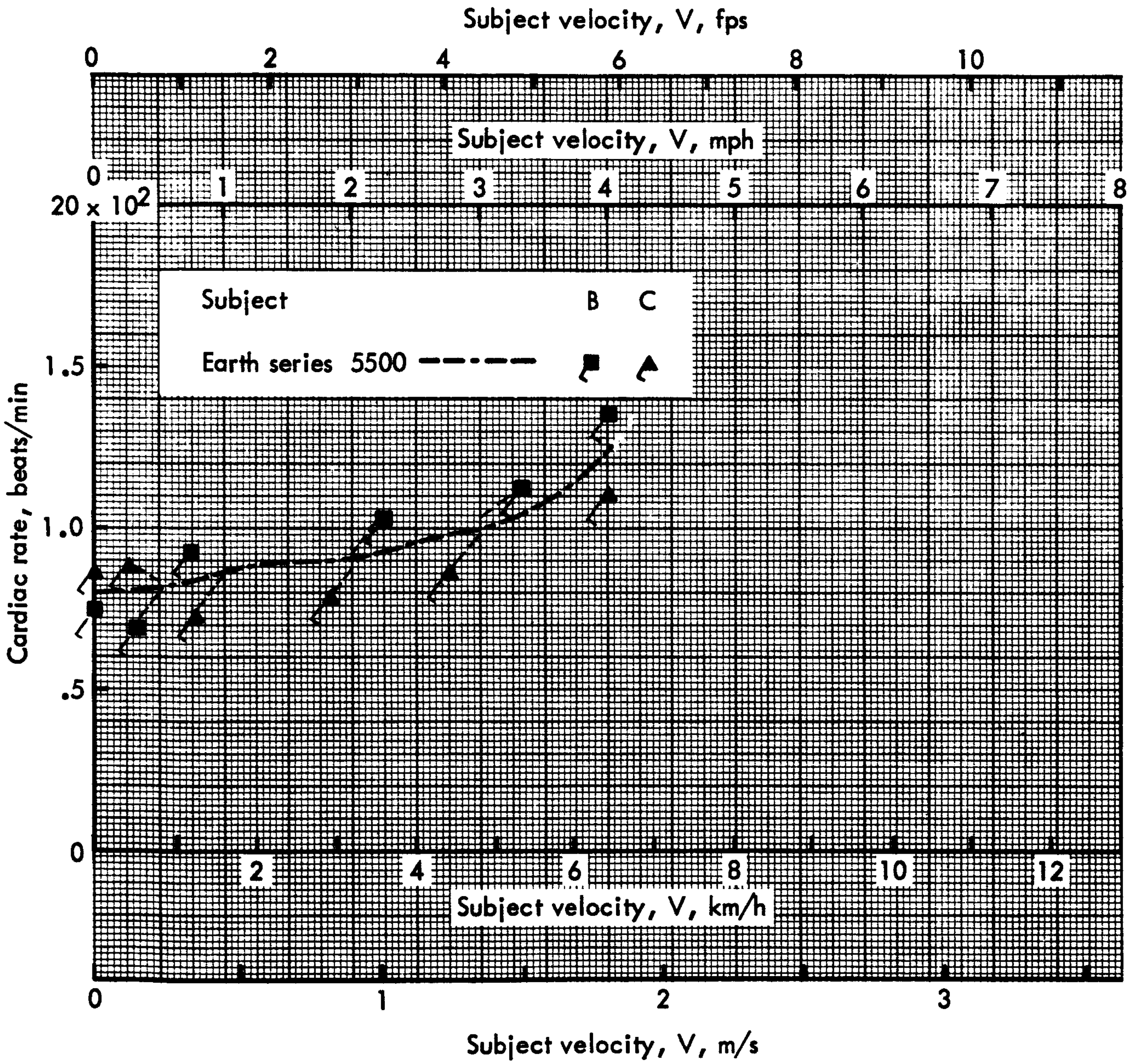


Figure 64. – Average cardiac rate versus subject velocity walking horizontally.
Test Conditions: 1 g, shirtsleeve, no susp. gear, no pack

Test Series 6000

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking	Work Variable	horizontally
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	6	6	12

Respiration, respiratory rate	Figure 66
respiratory volume expired	Figure 67
Metabolism, metabolic energy expenditure rate	Figure 68
metabolic energy expenditure rate per unit length	Not Obtained
oxygen consumption	Figure 69
oxygen consumption per unit length	Not Obtained
Cardiovascular function, cardiac rate	Figure 70
Body temperature, mean body temperature	Figure 71
Pressure suit environmental data	Not Obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 65. In Figure 65, the subject is wearing the suspension gear, and is also carrying Instrument Pack I with the respirometer. Note the globe thermometer on the framework next to the subject, and the earphone-microphone sets worn by the two operators (are inside the control center) which enable communication between themselves and with the subject.

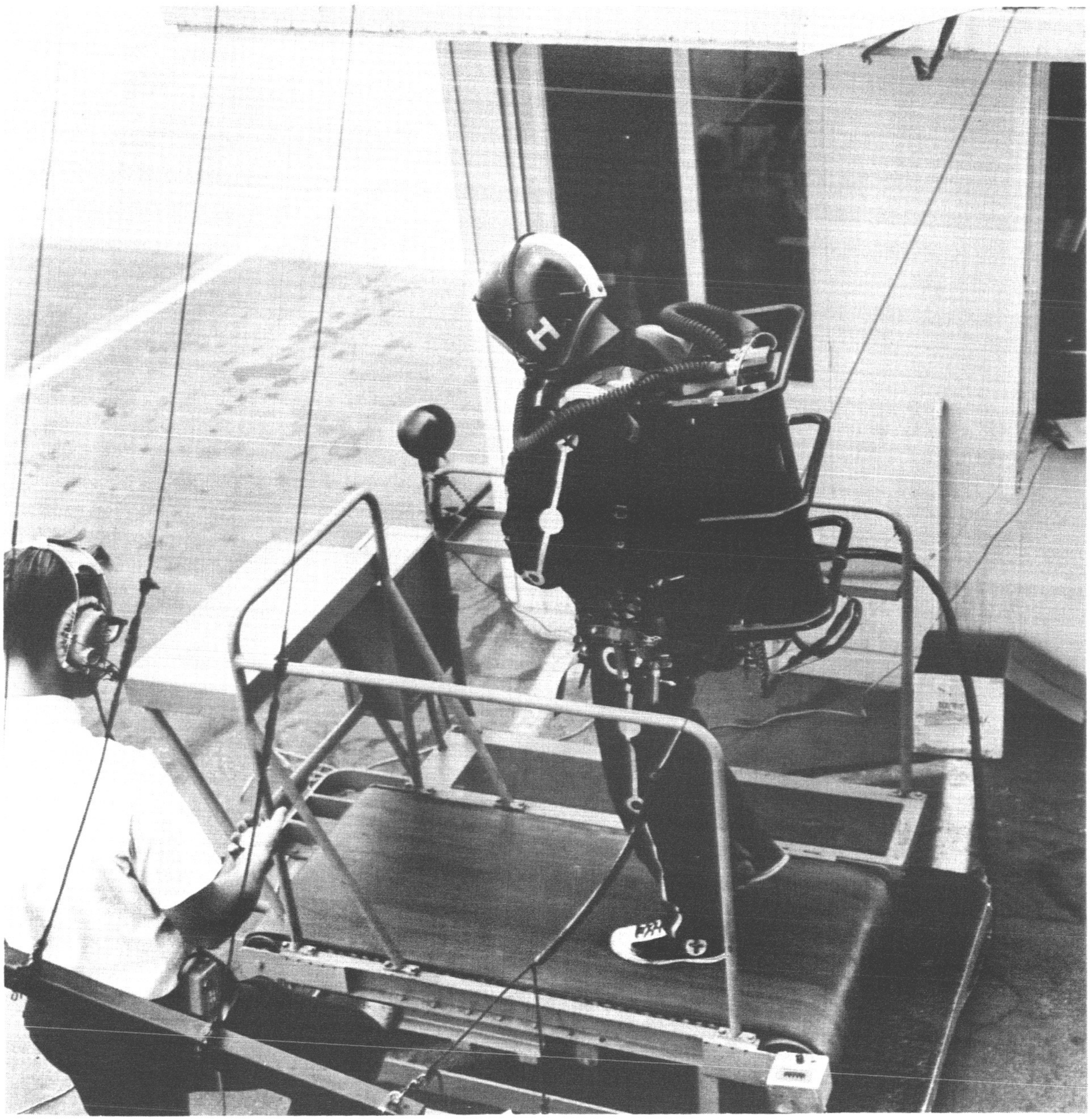


Figure 65. - Illustration of test arrangement for test series 6000

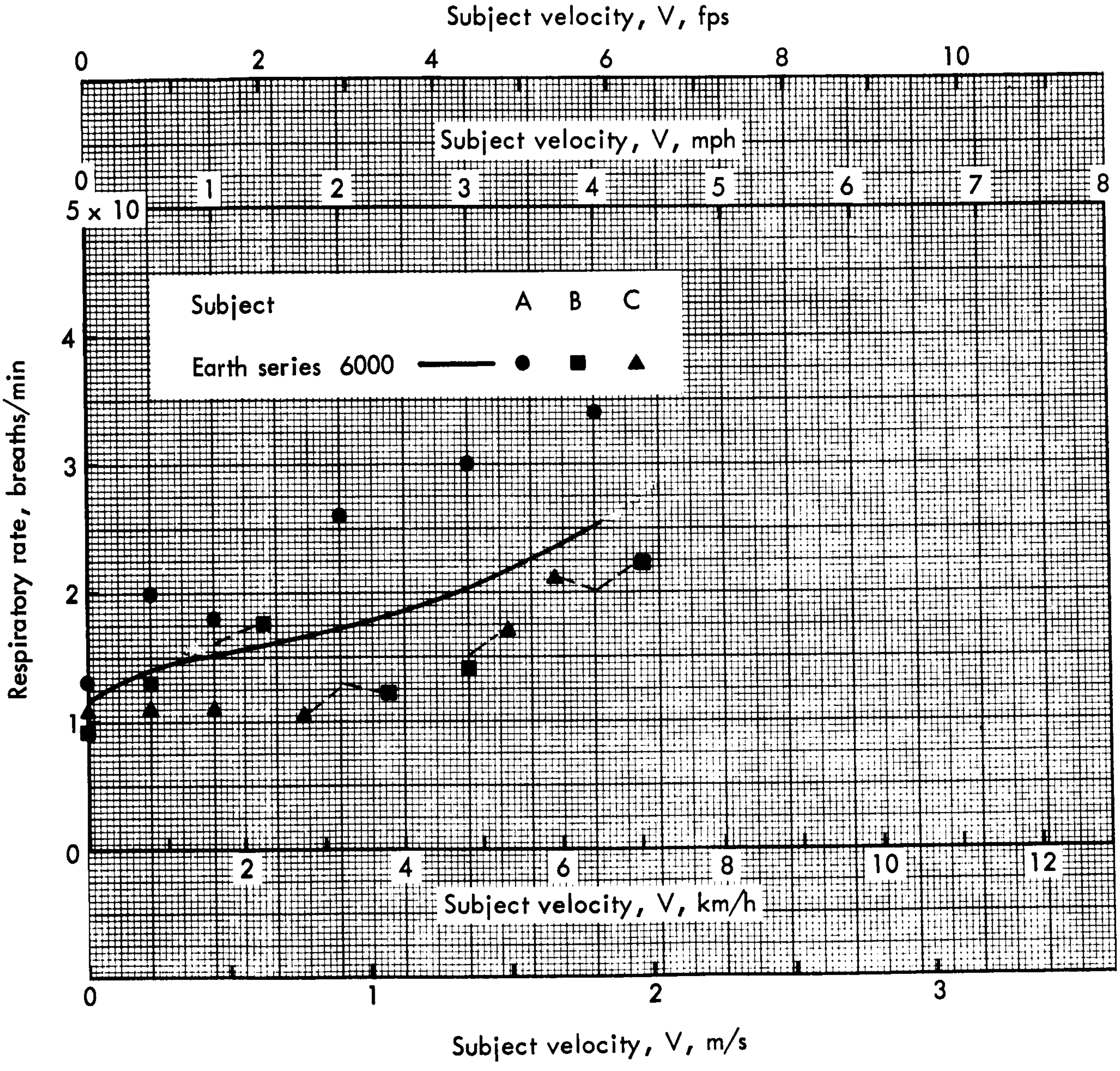


Figure 66. – Average respiratory rate versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

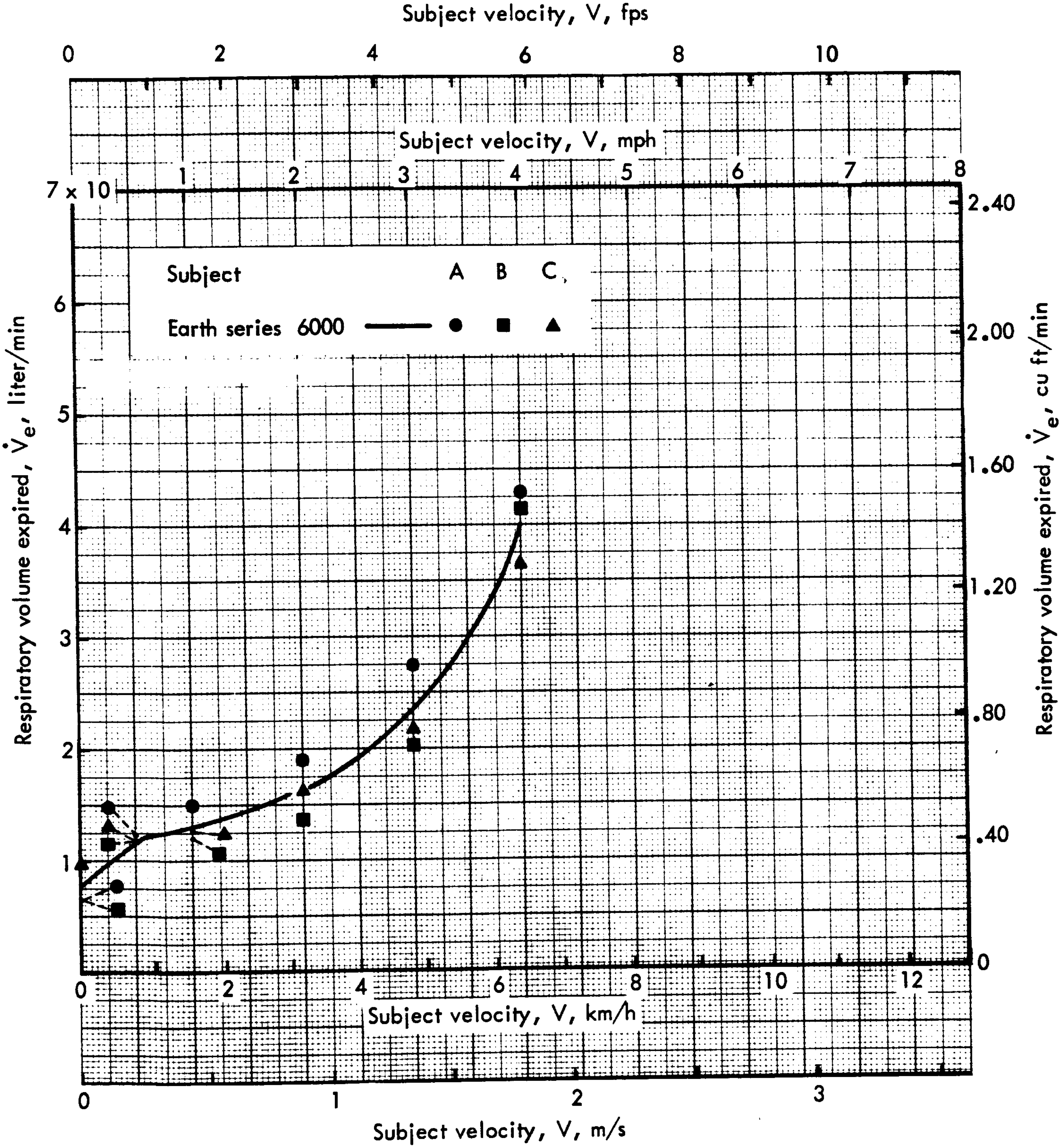


Figure 67. – Average mean respiratory volume versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

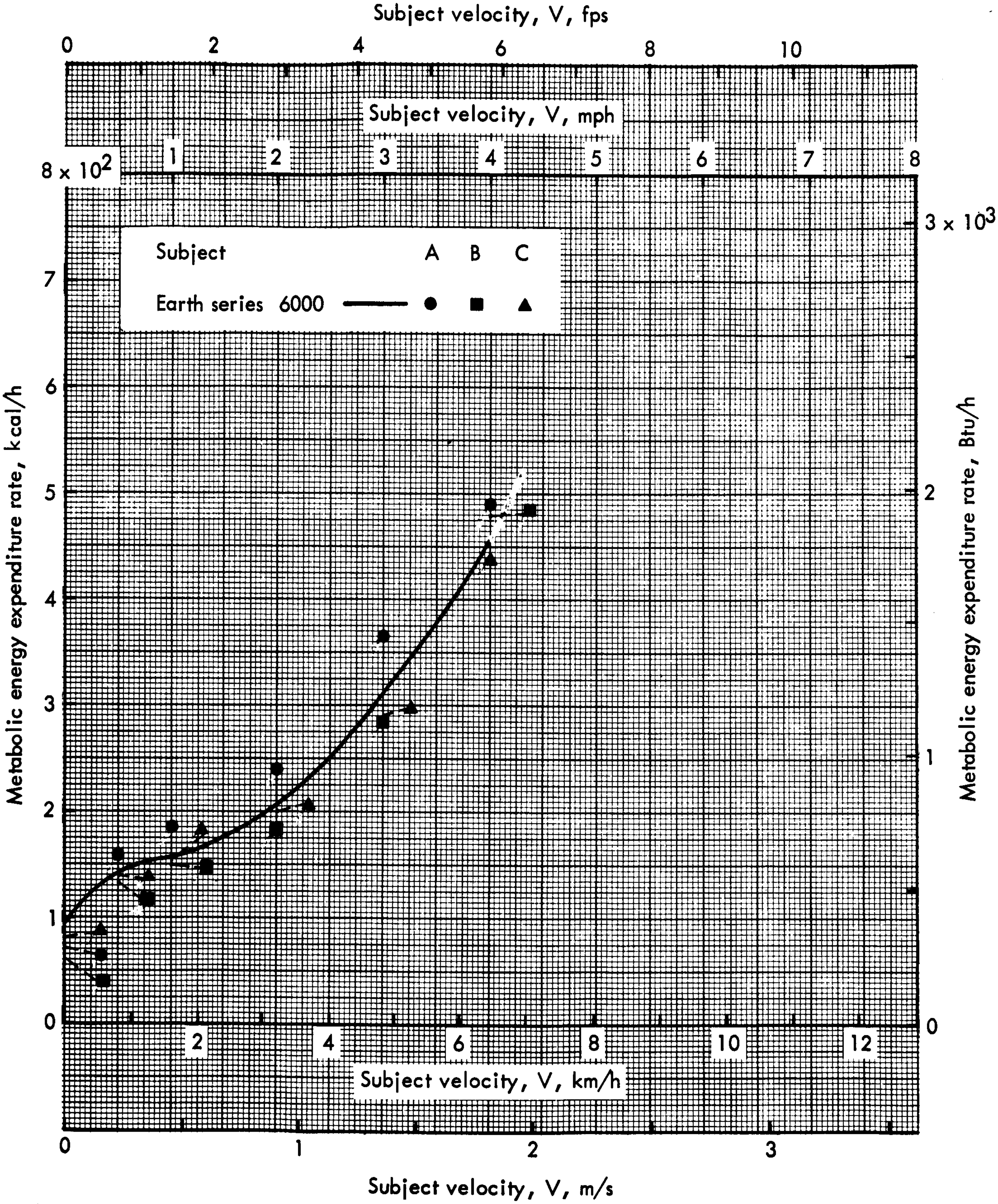


Figure 68. – Average metabolic energy expenditure rate versus subject velocity walking horizontally

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

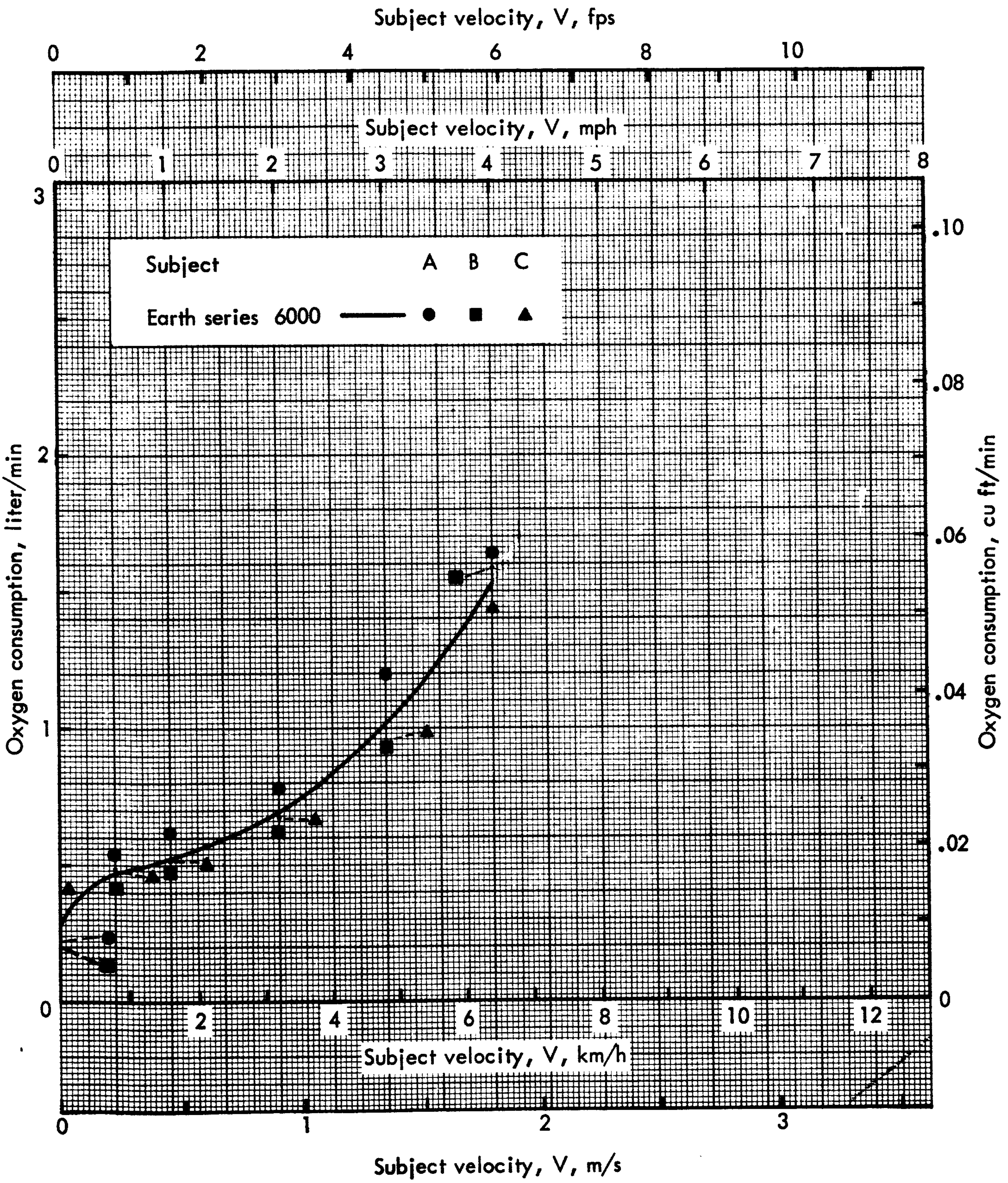


Figure 69. – Average oxygen consumption versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

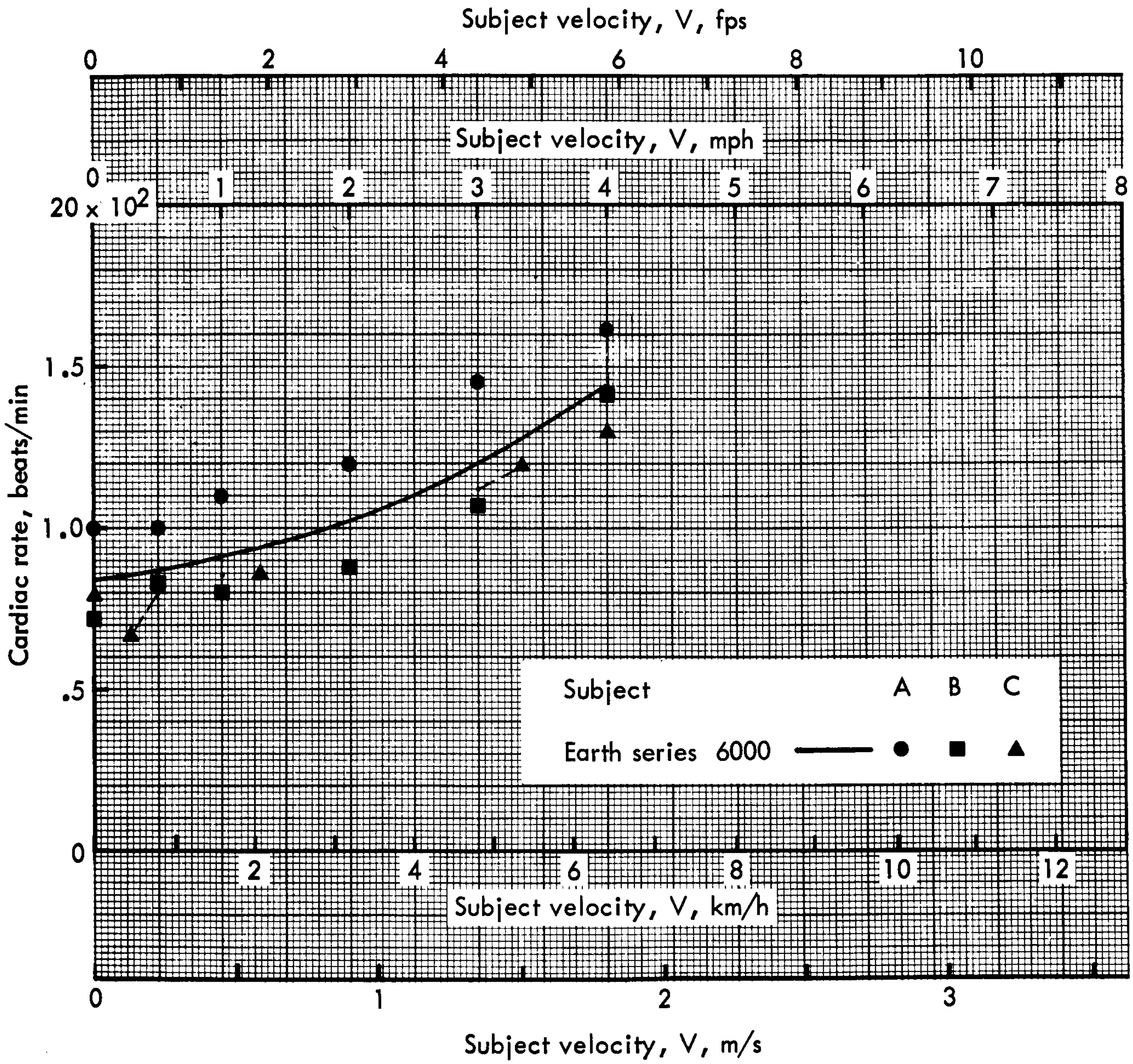


Figure 70. – Average cardiac rate versus subject velocity walking horizontally.
Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

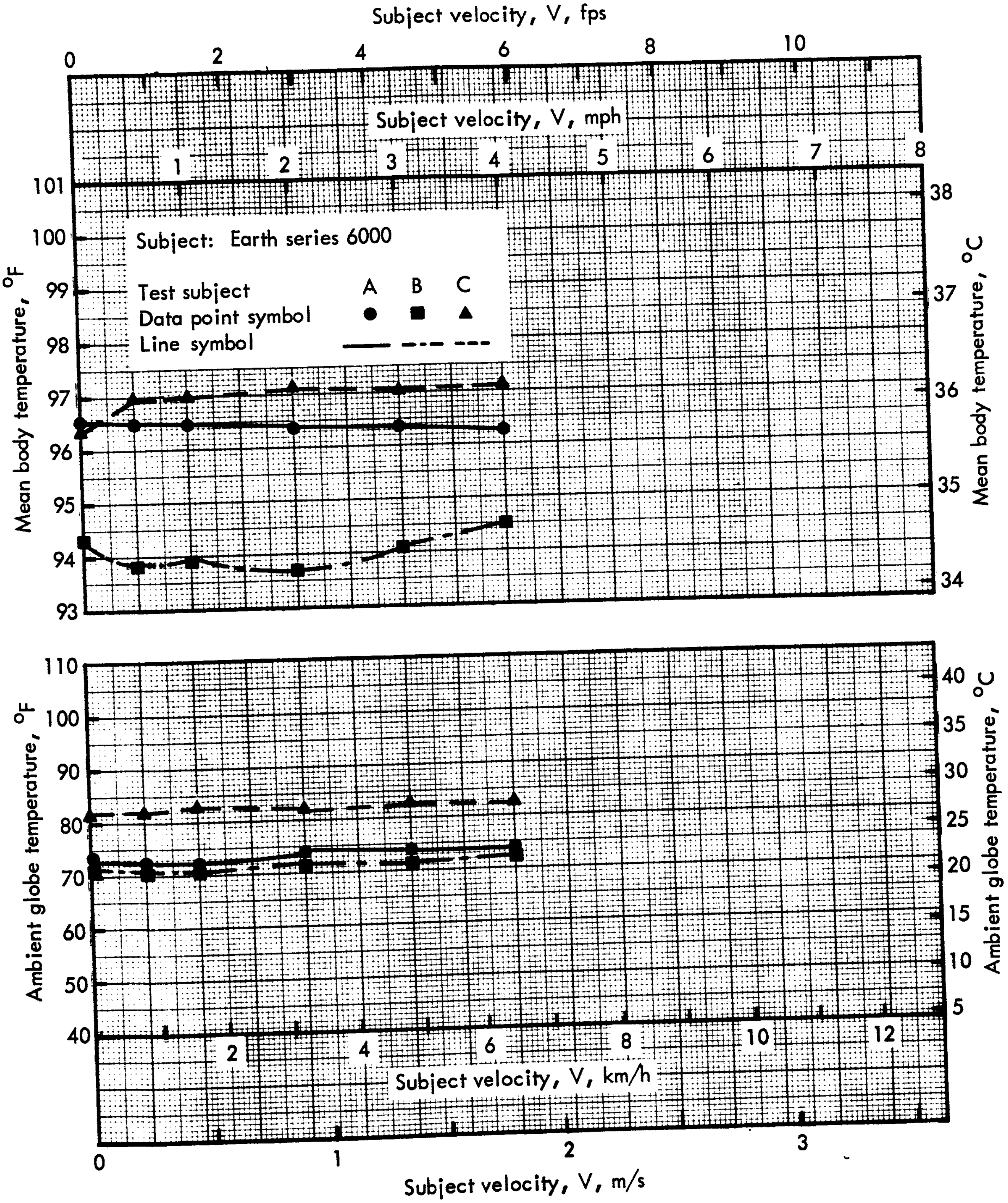


Figure 71. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

Test Series 6500

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	none, but suspension gear	Instrument Pack II	
Work Activity	walking	Work Variable	horizontally
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	6		12

Respiration,	respiratory rate	Figure 73*
	respiratory volume expired	Figure 74
Metabolism,	metabolic energy expenditure rate	Figure 75
	metabolic energy expenditure rate per unit length	Not Obtained
	oxygen consumption	Not Obtained
	oxygen consumption per unit length	Figure 76
Cardiovascular function,	cardiac rate	Figure 77
Body temperature,	mean body temperature	Not Obtained
Pressure suit environmental data		Not Obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 72. Figure 72 shows a shirtsleeve test with the suspension gear added.

*Respiratory rate for Subject A was not obtained at 2.0 and 3.0 mph

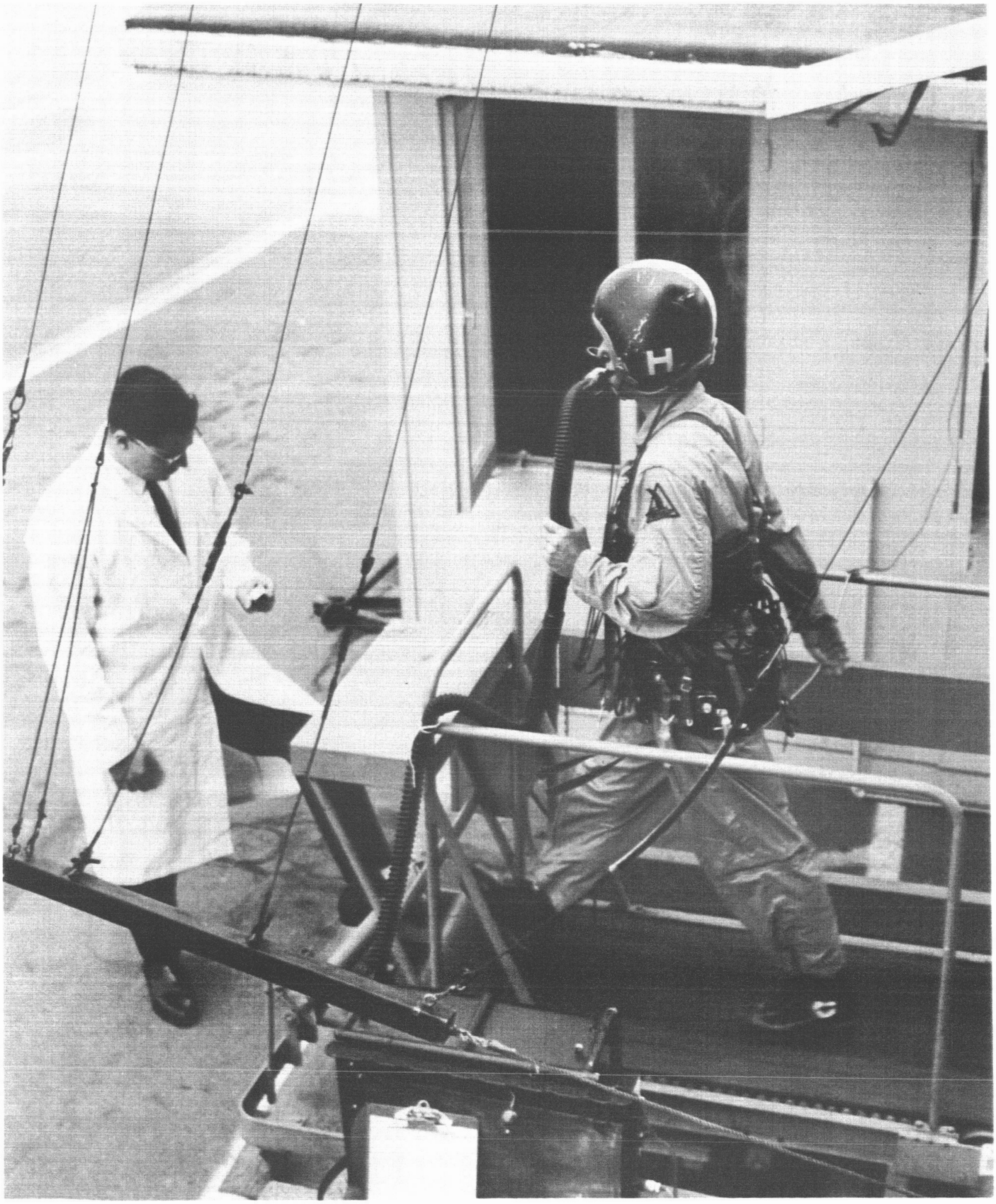


Figure 72. – Illustration of test arrangement for test series 6500.

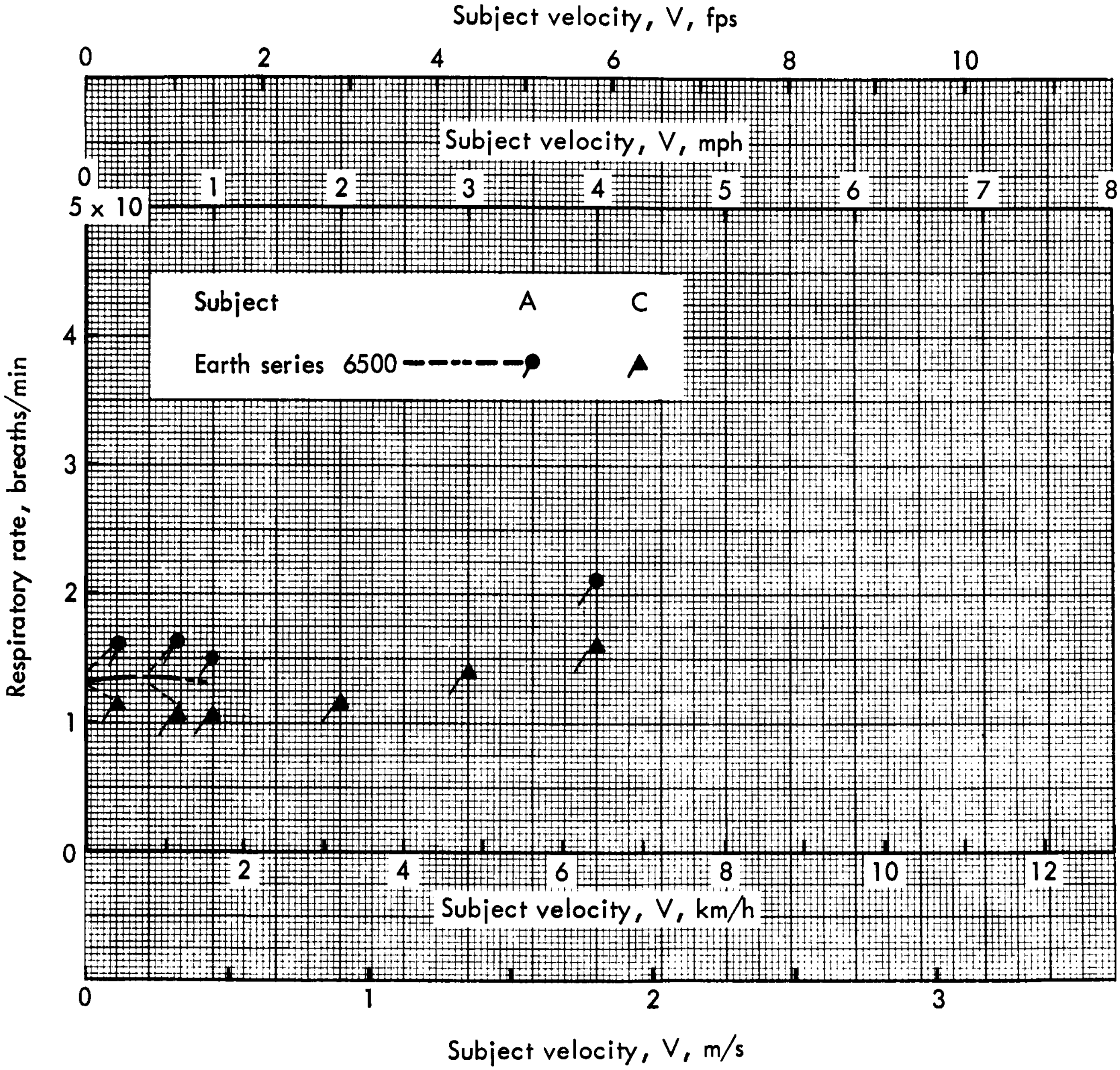


Figure 73. – Average respiratory rate versus subject velocity walking horizontally.
Test conditions: 1 g, shirtsleeve, susp. gear, no pack

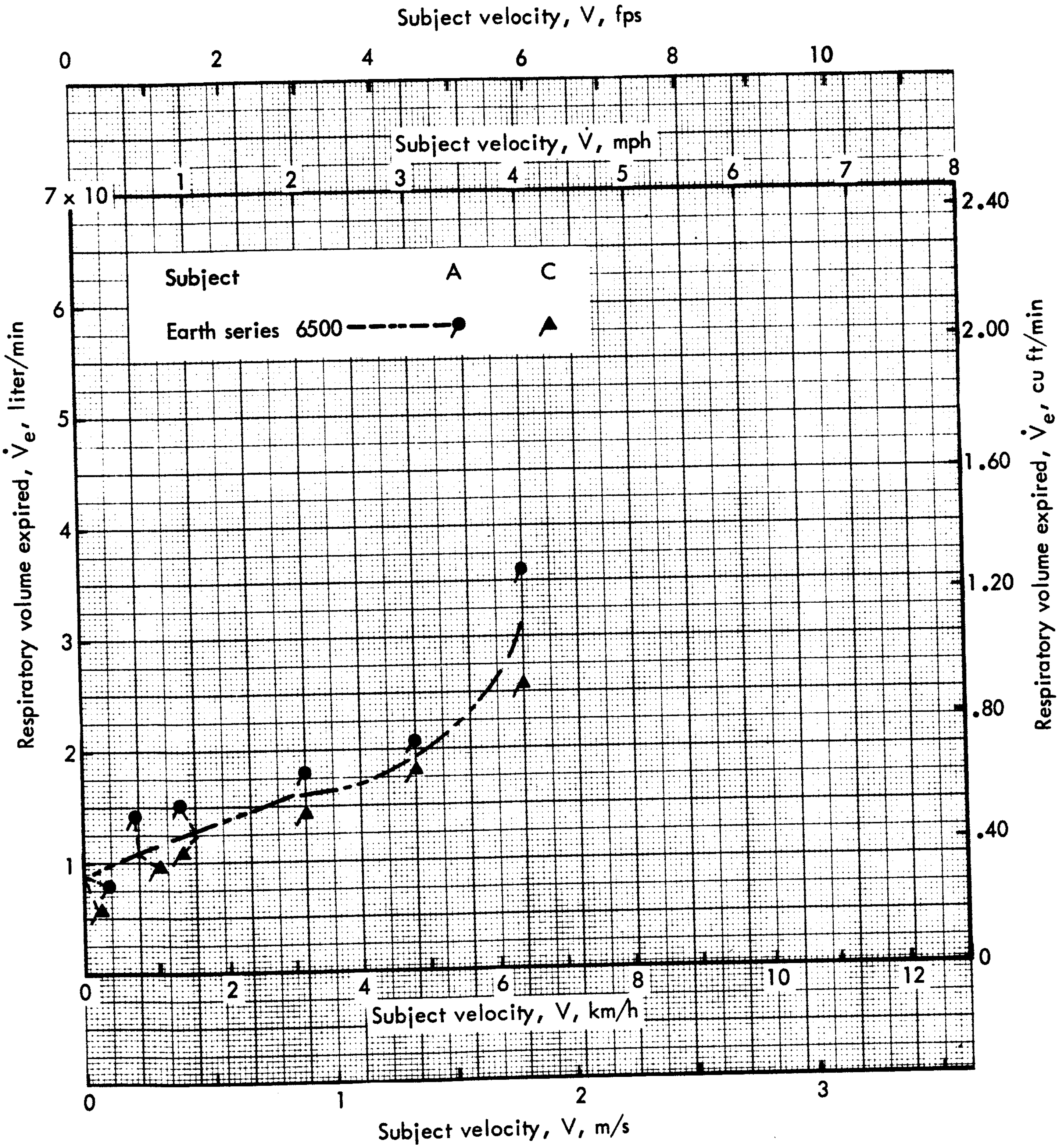


Figure 74. – Average mean respiratory volume versus subject velocity walking horizontally.
Test conditions: 1 g, shirtsleeve, susp. gear, no pack

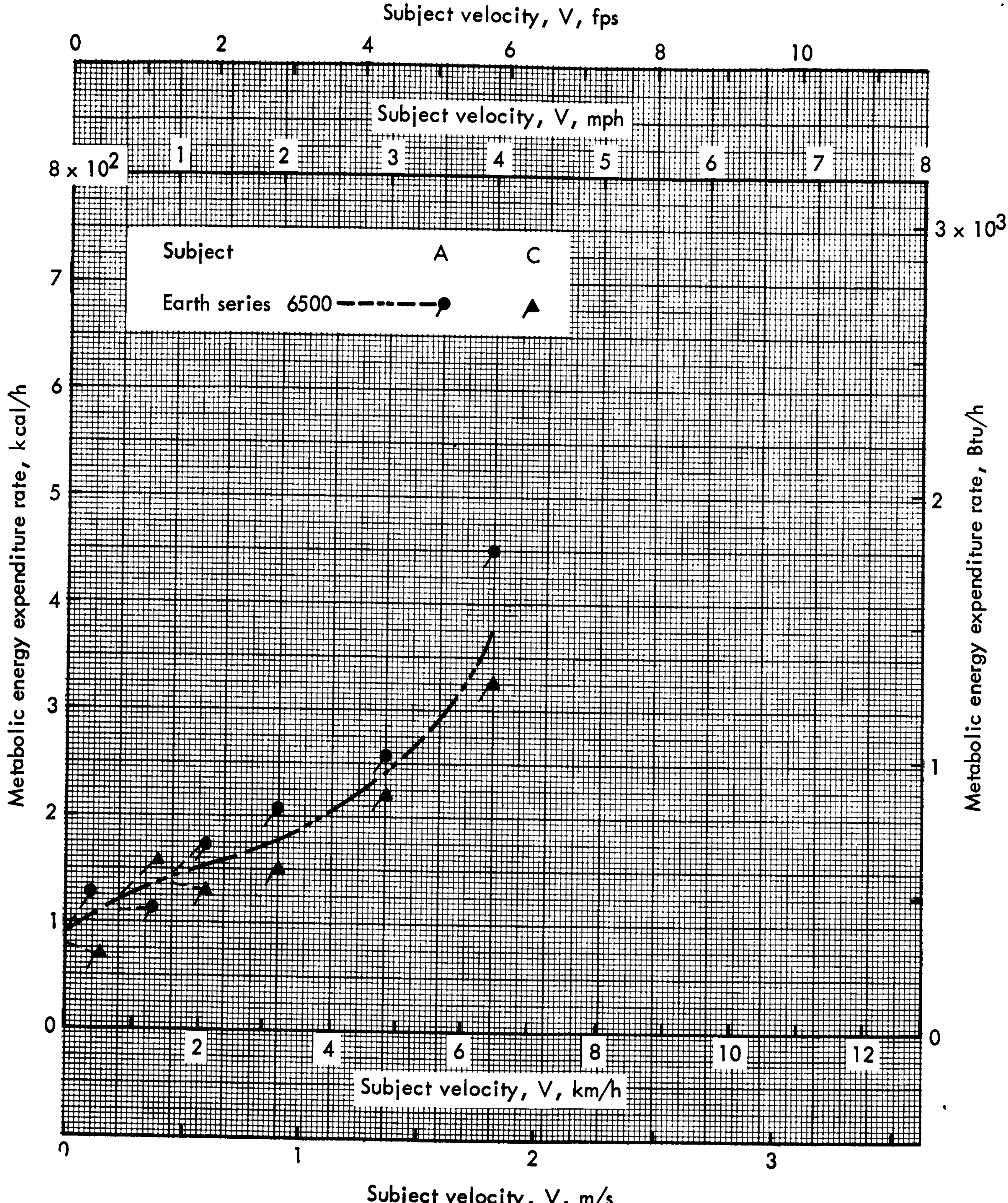


Figure 75. – Average metabolic energy expenditure rate versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, no pack

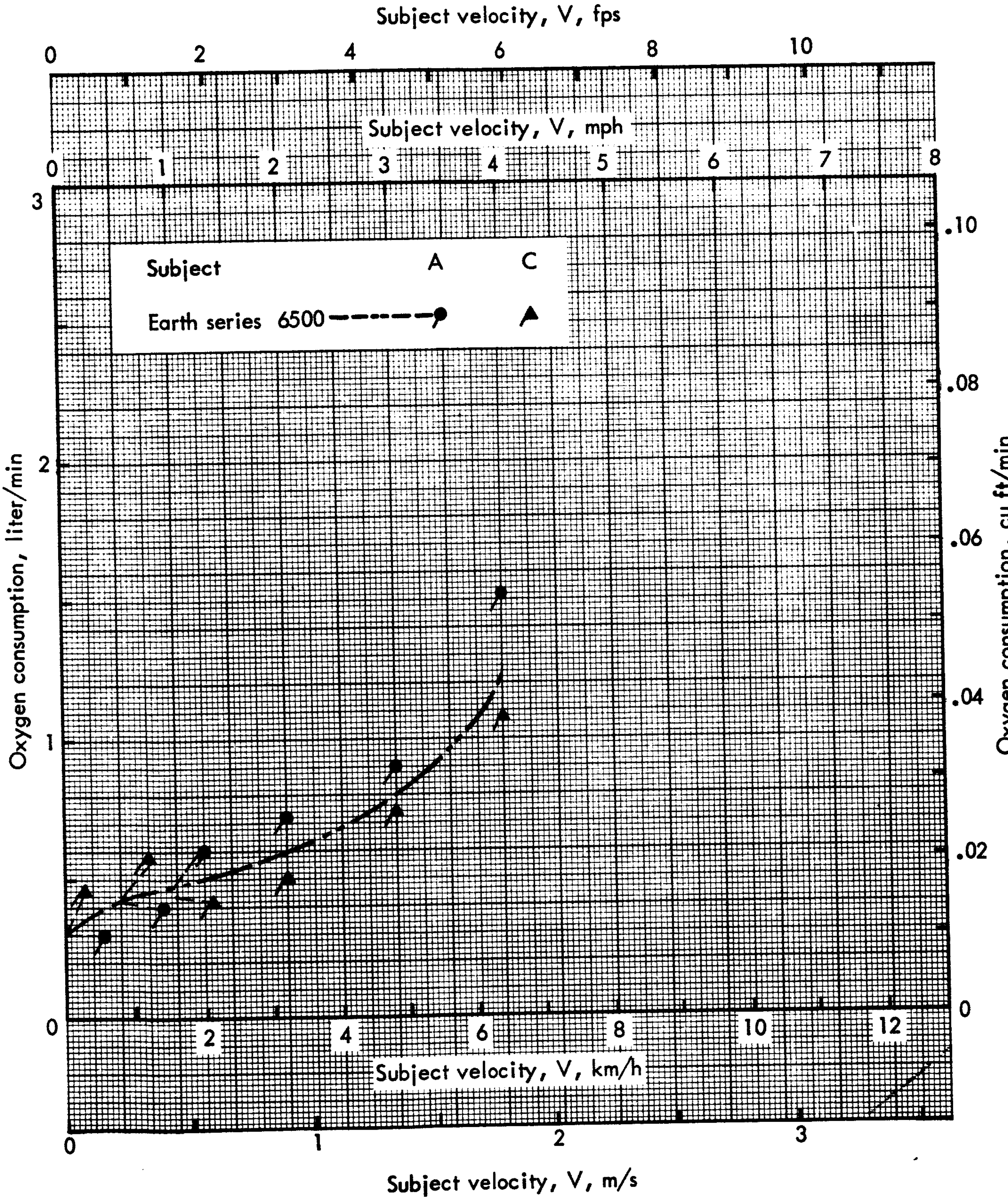


Figure 76. – Average oxygen consumption versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, no pack

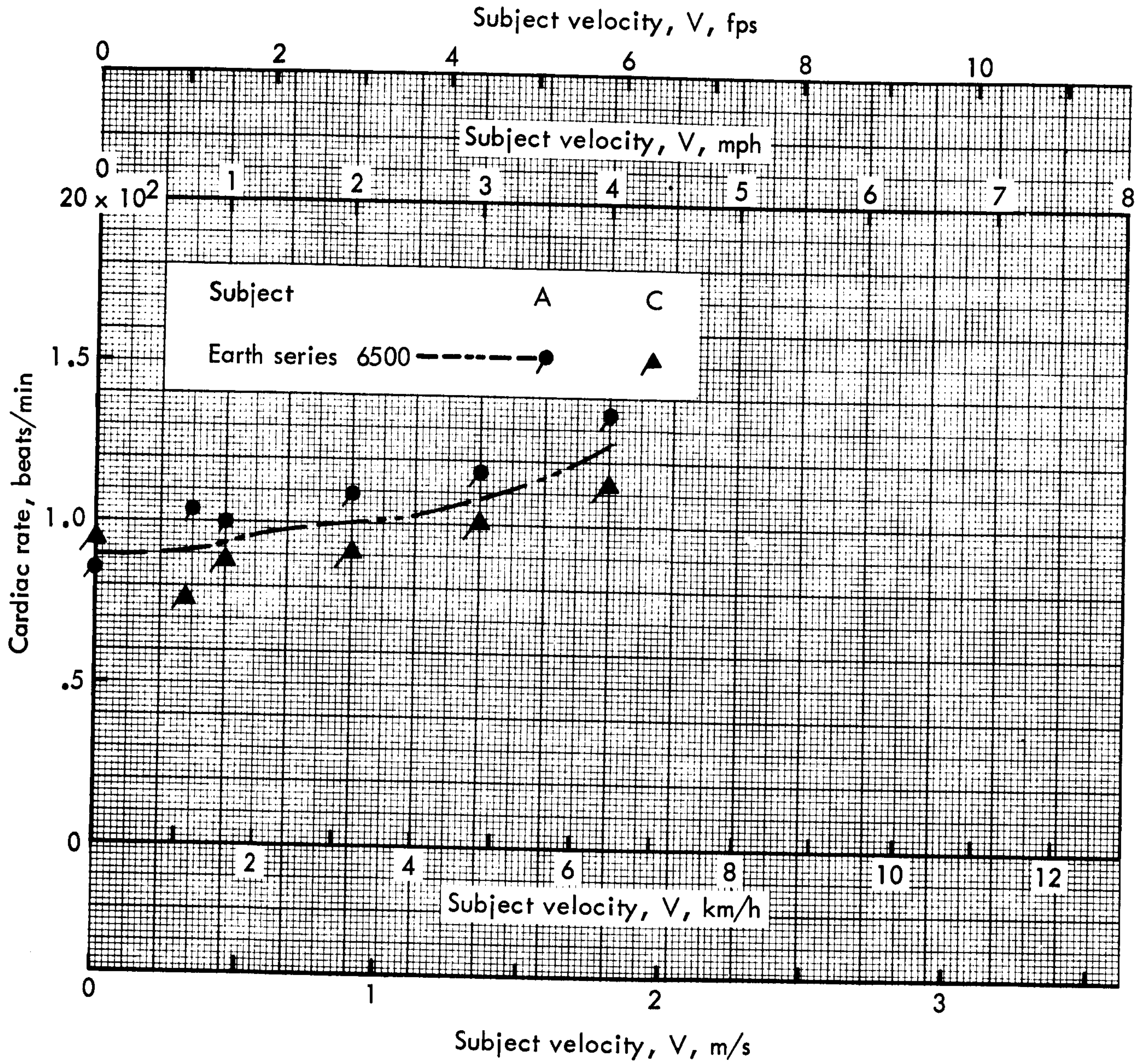


Figure 77. – Average cardiac rate versus subject velocity walking horizontally.

Test Conditions: 1 g, shirtsleeve, susp. gear, no pack

Test Series 7000

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	horizontally
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	6		6

Respiration,	respiratory rate	Figure 79
	respiratory volume expired	Figure 80
Metabolism,	metabolic energy expenditure rate	Figure 81
	metabolic energy expenditure rate per unit length	Not Obtained
	oxygen consumption	Figure 82
	oxygen consumption per unit length	Not Obtained
Cardiovascular function, cardiac rate		Figure 83
Body temperature, mean body temperature		Figure 84
Pressure suit environmental data		Not Obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 78. In Figure 78, the subject is wearing the pressure suit, with ventilation flow only, controlled by the ECS in Instrument Pack II, which he is carrying. His respiration and metabolic rate is monitored by the respirometer in Instrument Pack I, which rests on the frame ahead of him. The umbilical lines for the physiological monitoring circuits, communication, and air supply extend to the subject's rear.

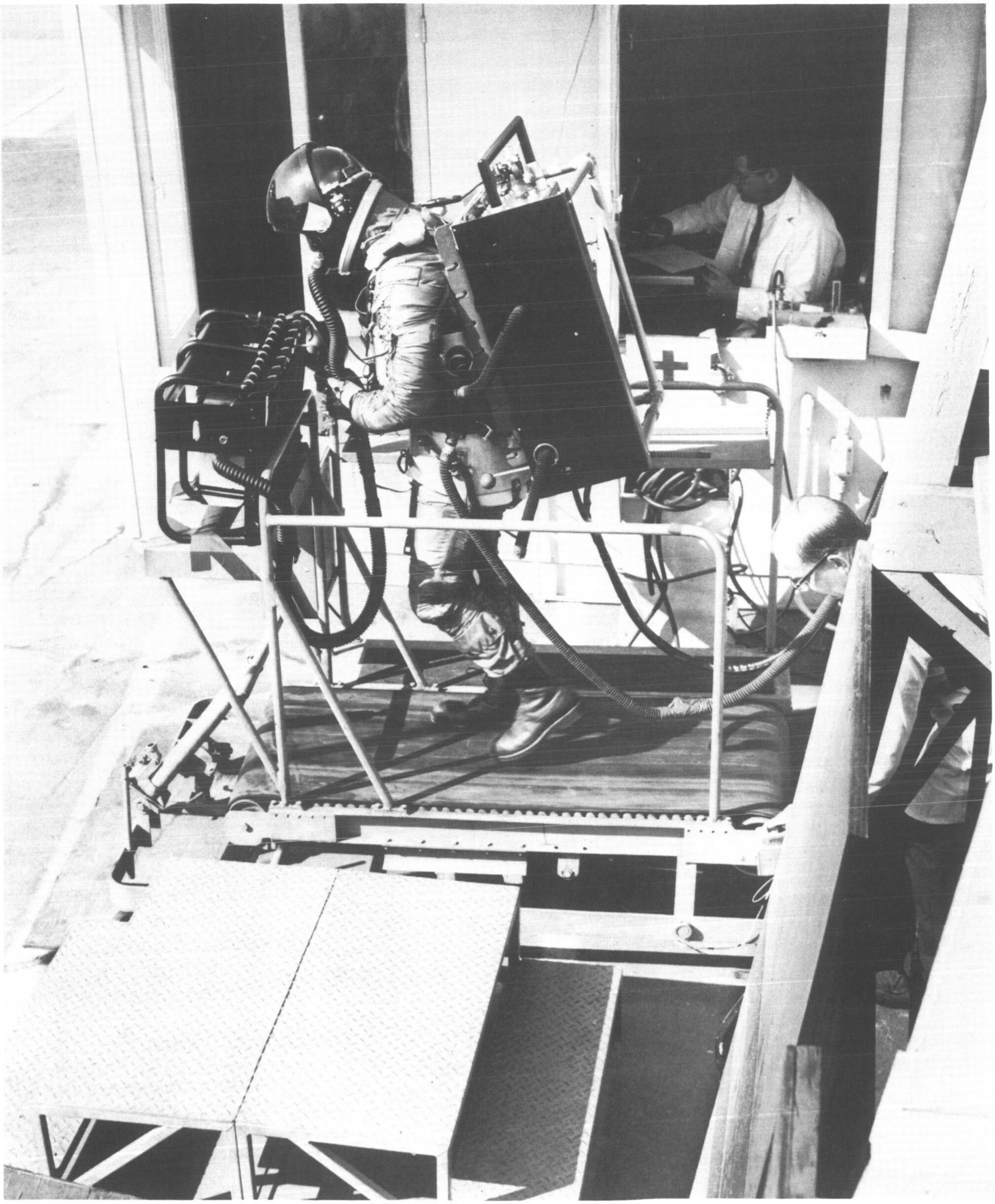


Figure 78. - Illustration of test arrangement for test series 7000

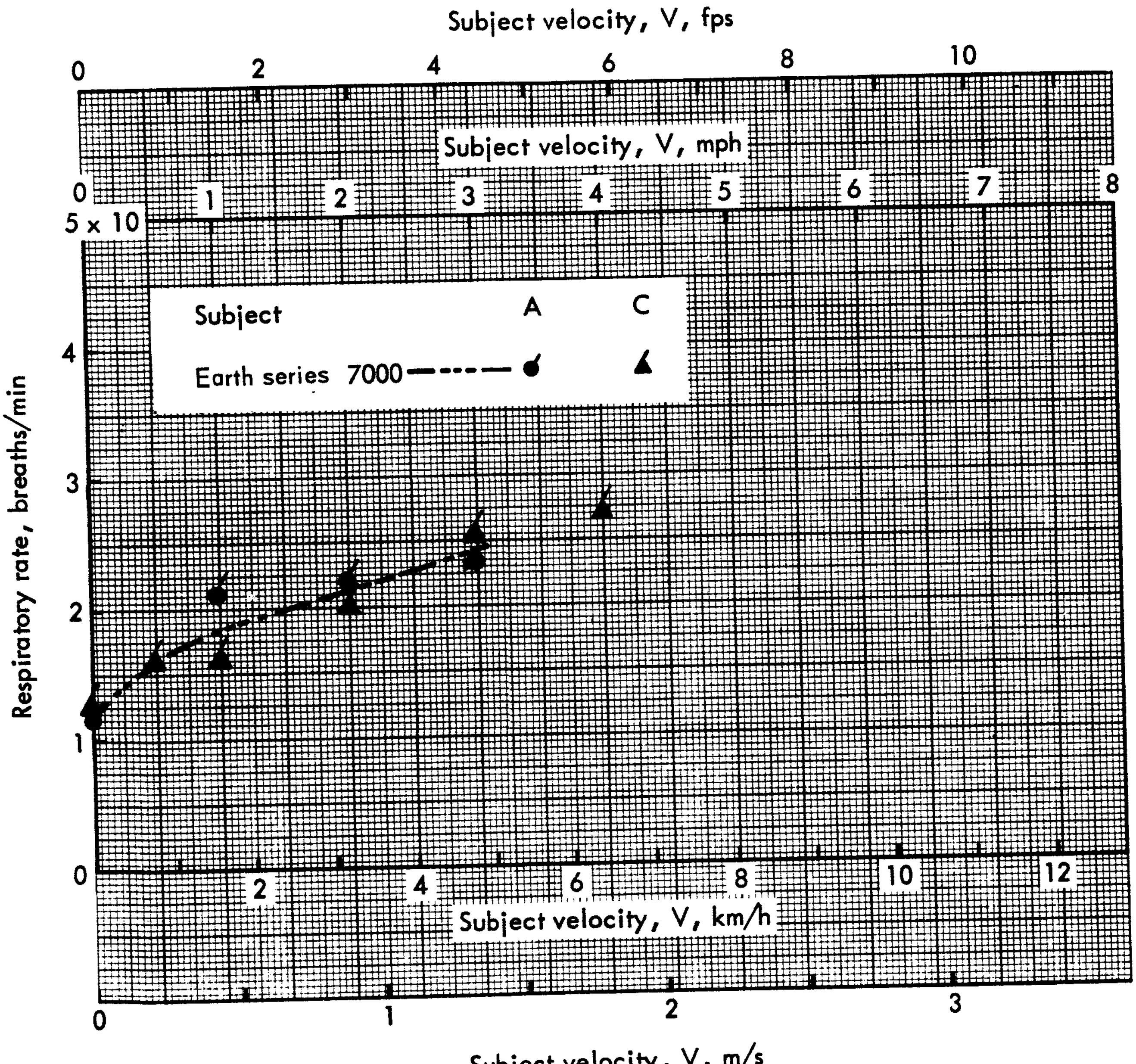


Figure 79. – Average respiratory rate versus subject velocity walking horizontally.
Test Conditions: 1 g, pressure suit-vent flow, susp. gear, pack II

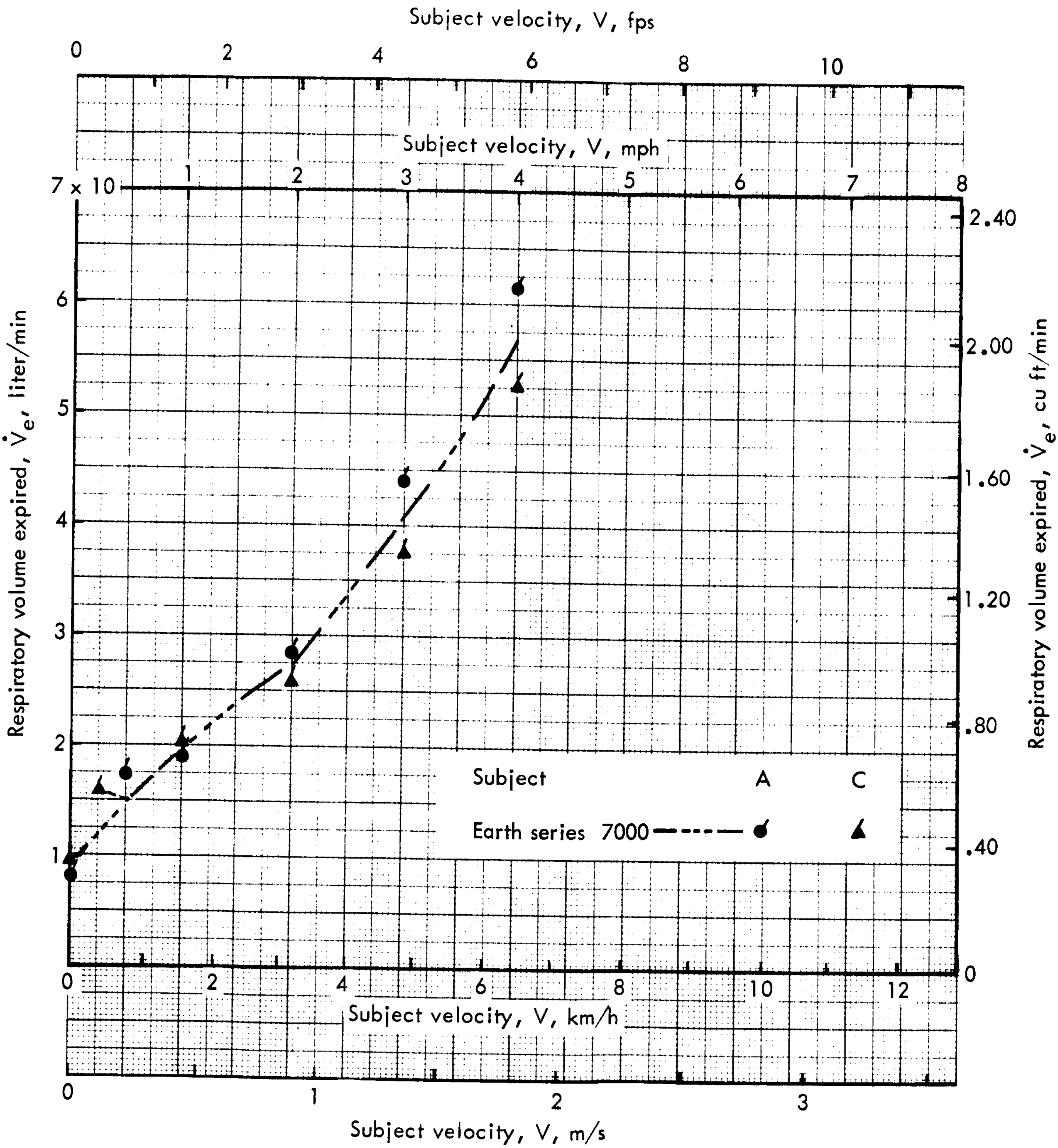


Figure 80. – Average mean respiratory volume versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-vent flow, susp. gear, pack II

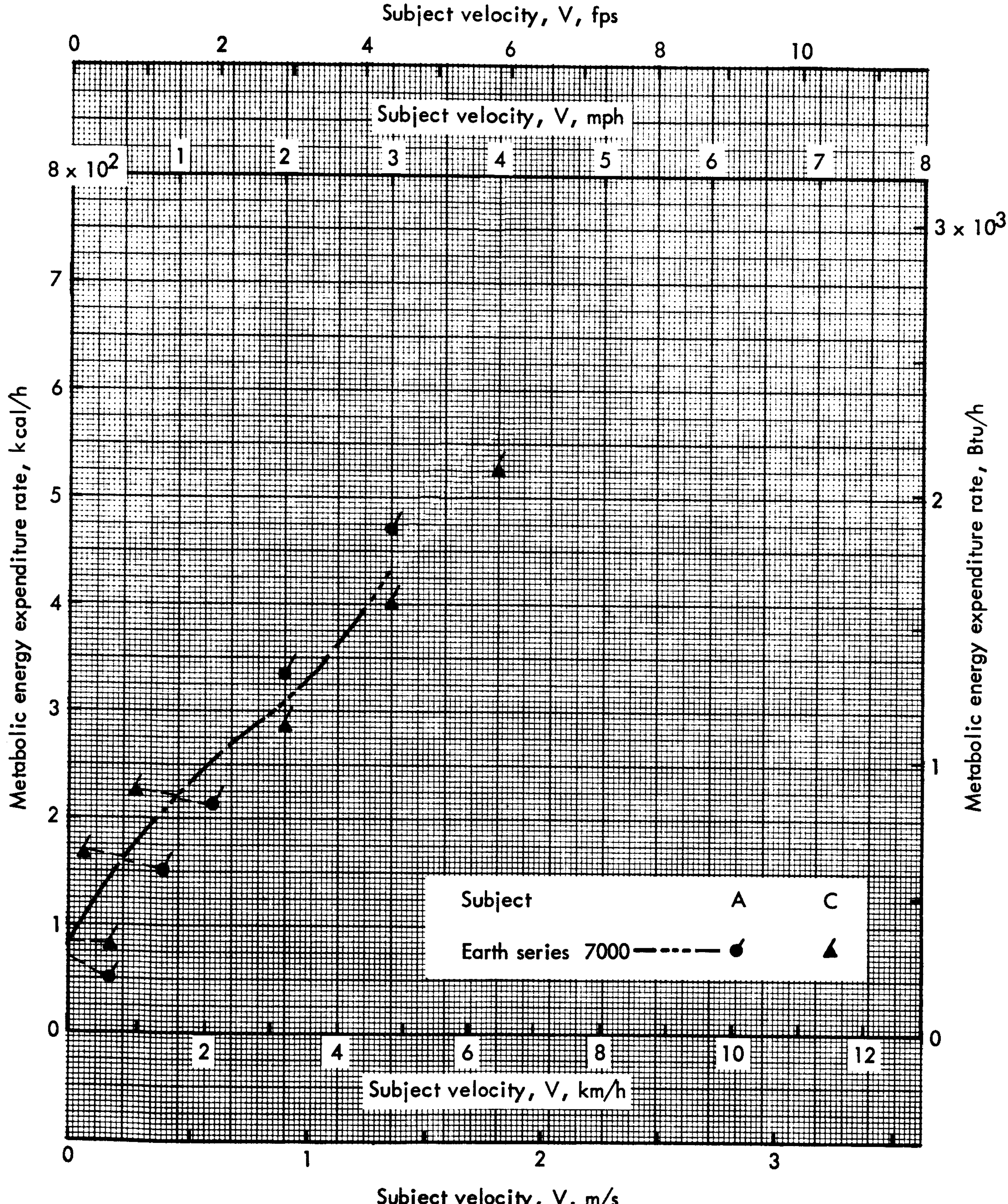


Figure 81. – Average metabolic energy expenditure rate versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-vent flow, susp. gear, pack II

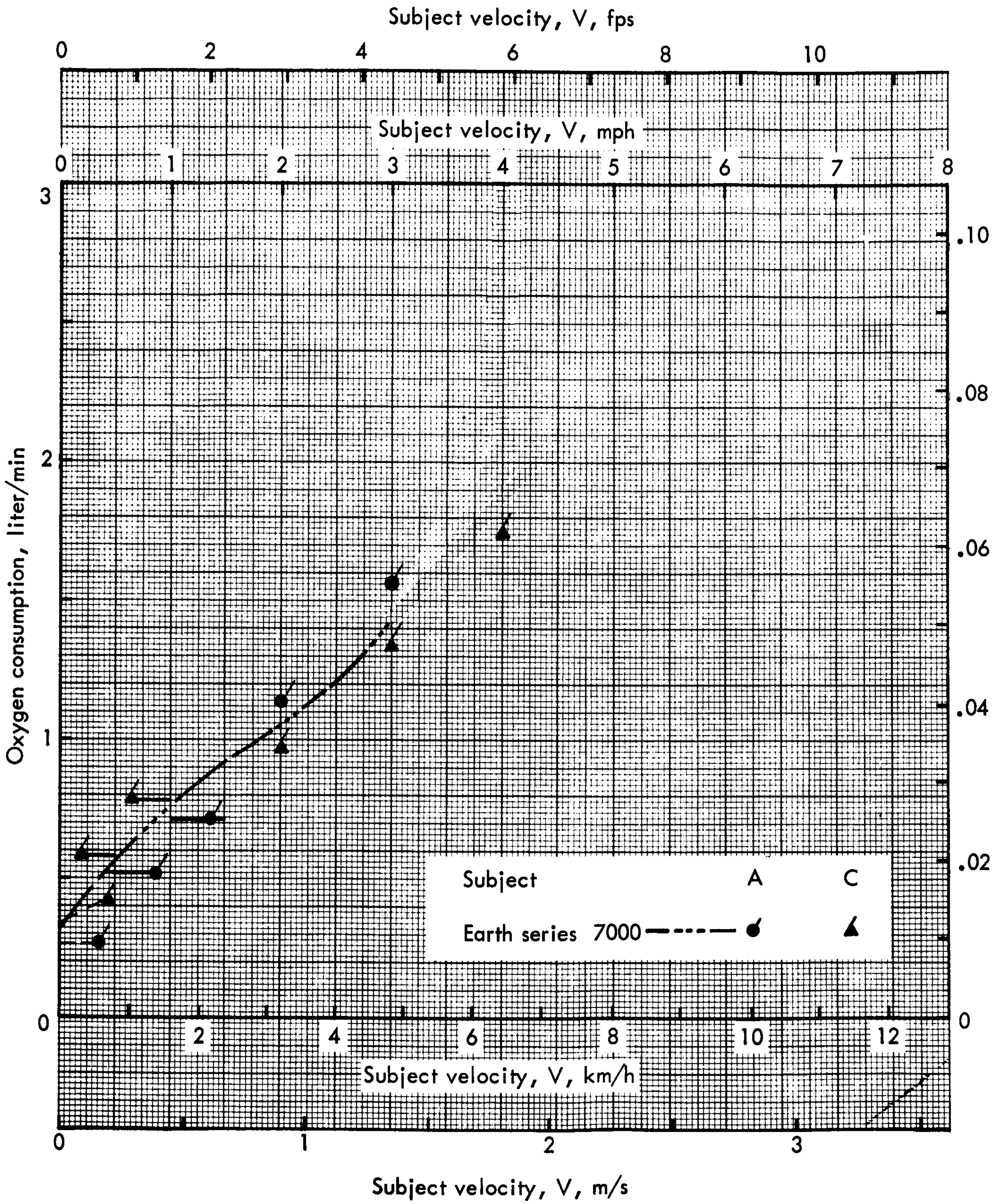


Figure 82. – Average oxygen consumption versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-vent flow, susp. gear, pack II

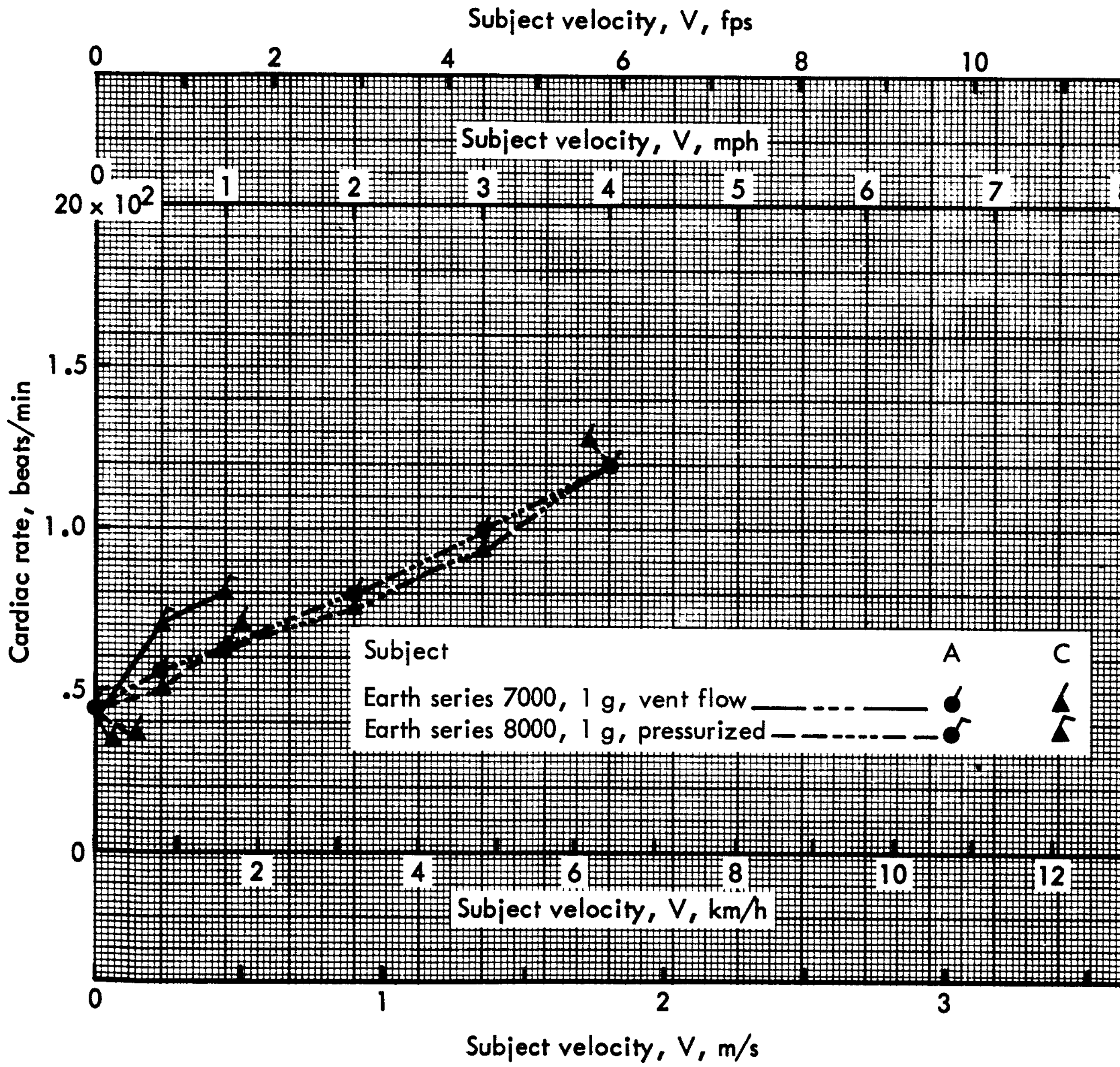


Figure 83. – Average cardiac rate versus subject velocity walking horizontally. Test Conditions: Comparison of 1 g, test conditions between vent flow and pressure

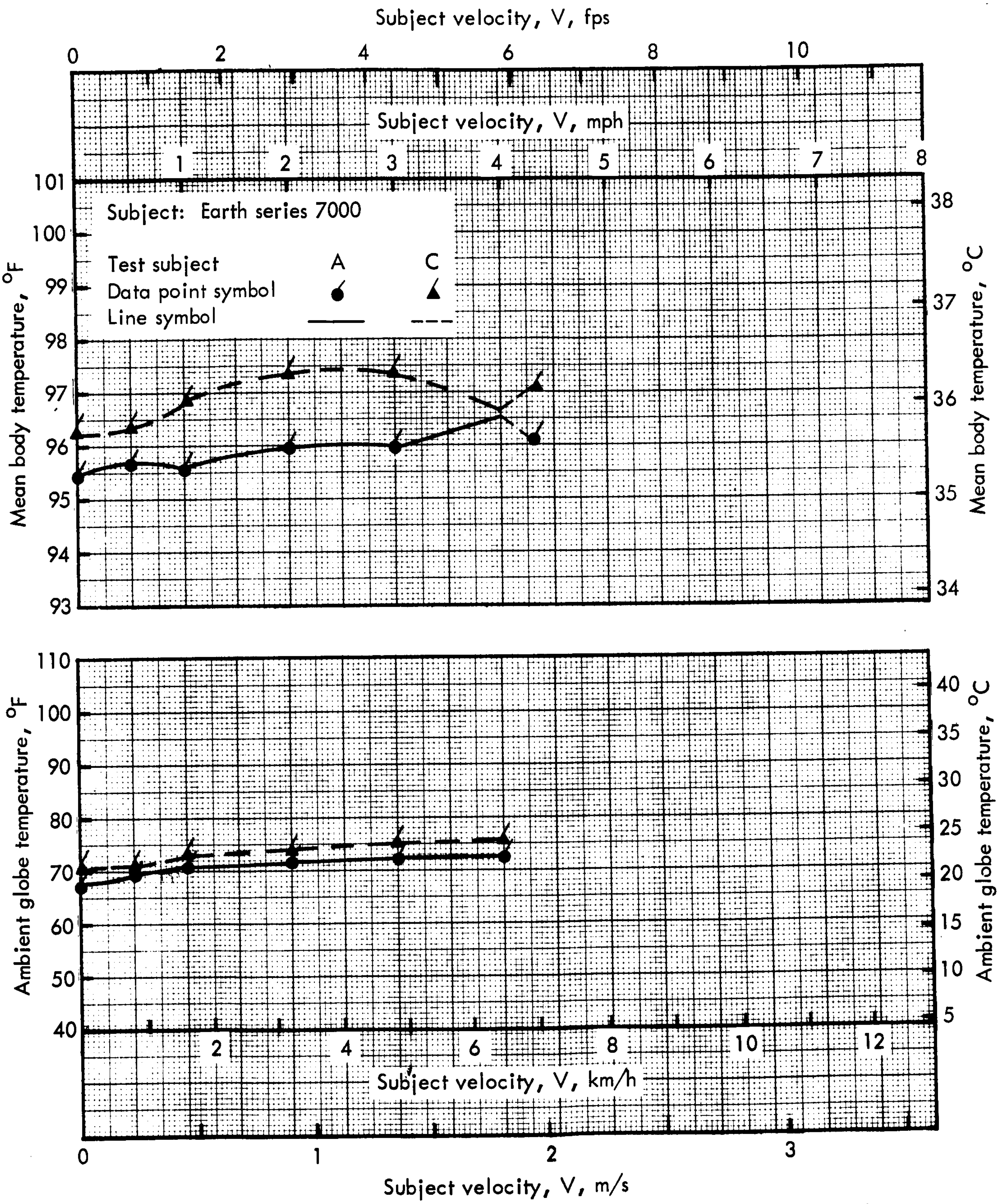


Figure 84. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-vent flow, susp. gear, pack II

Test Series 8000

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	horizontally
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	3		3

Respiration, respiratory rate	Figure 86
respiratory volume expired	Figure 87
Metabolism, metabolic energy expenditure rate	Figure 88
metabolic energy expenditure rate per unit length	Not Obtained
oxygen consumption	Figure 89
oxygen consumption per unit length	Not Obtained
Cardiovascular function, cardiac rate	Figure 83
Body temperature, mean body temperature	Figure 90
Pressure suit environmental data	Figure 91

Comments:

The arrangement for the tests conducted in this series is shown in Figure 85 .

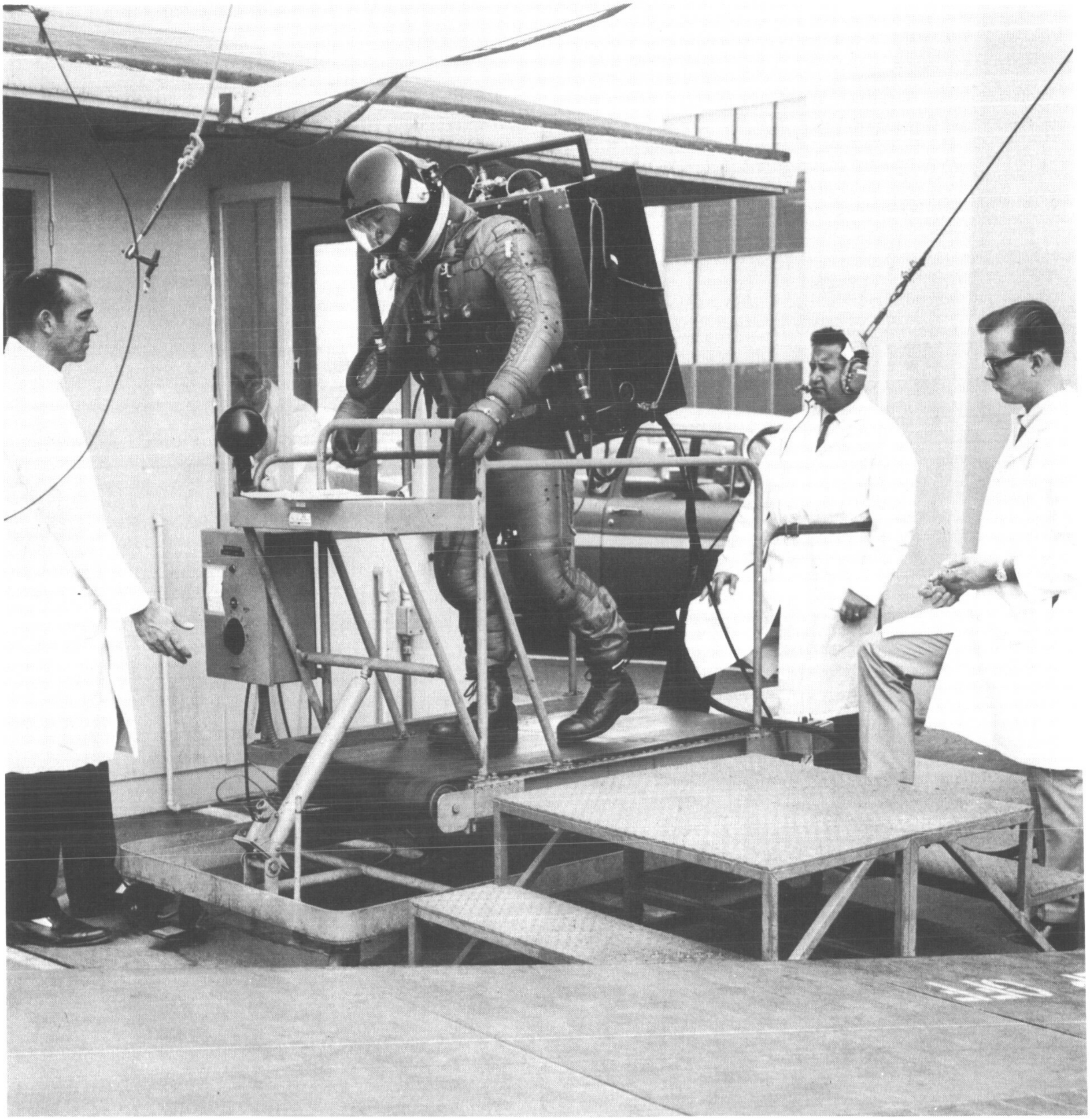


Figure 85. - Illustration of test arrangement for test series 8000

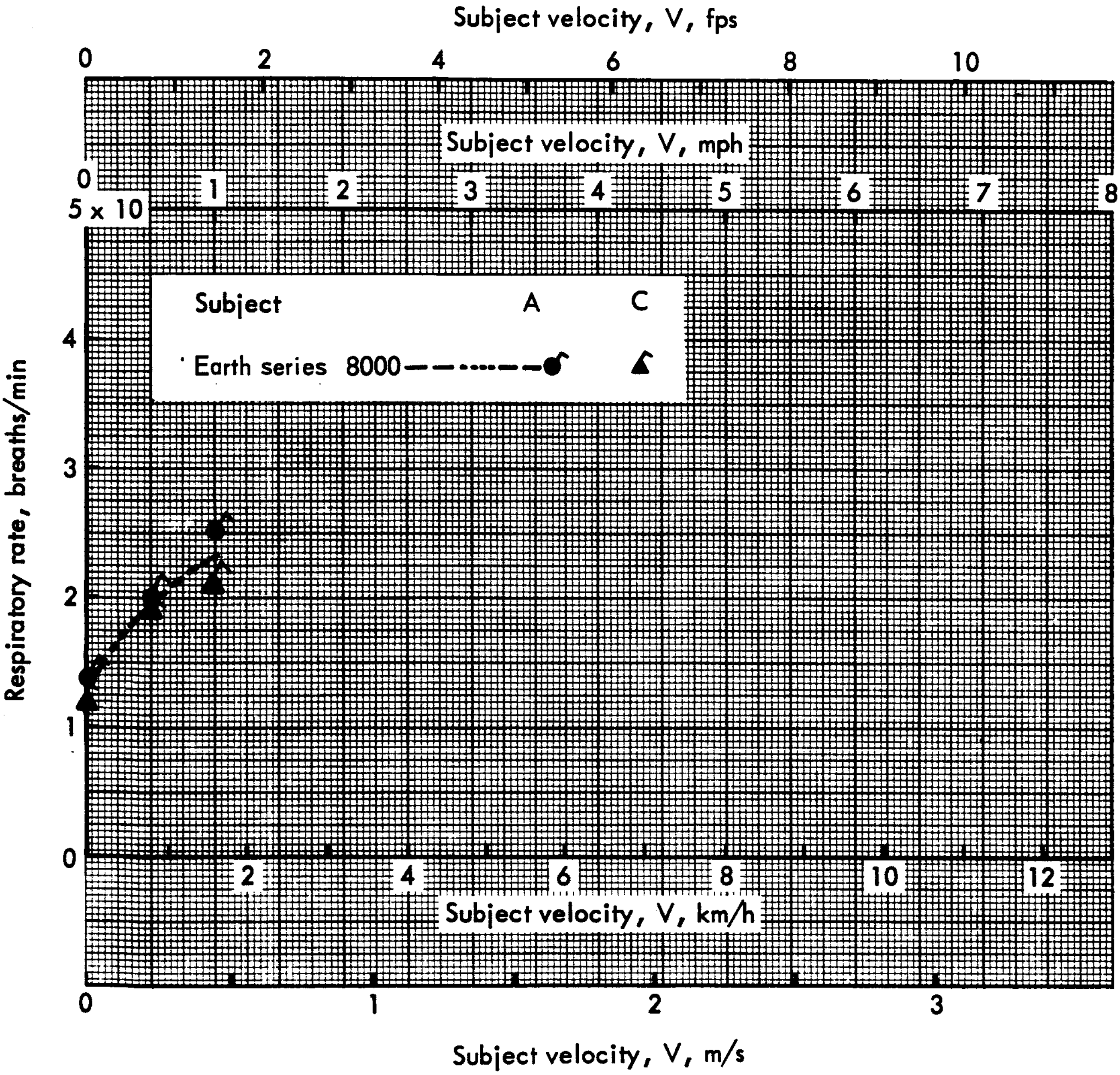


Figure 86. – Average respiratory rate versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

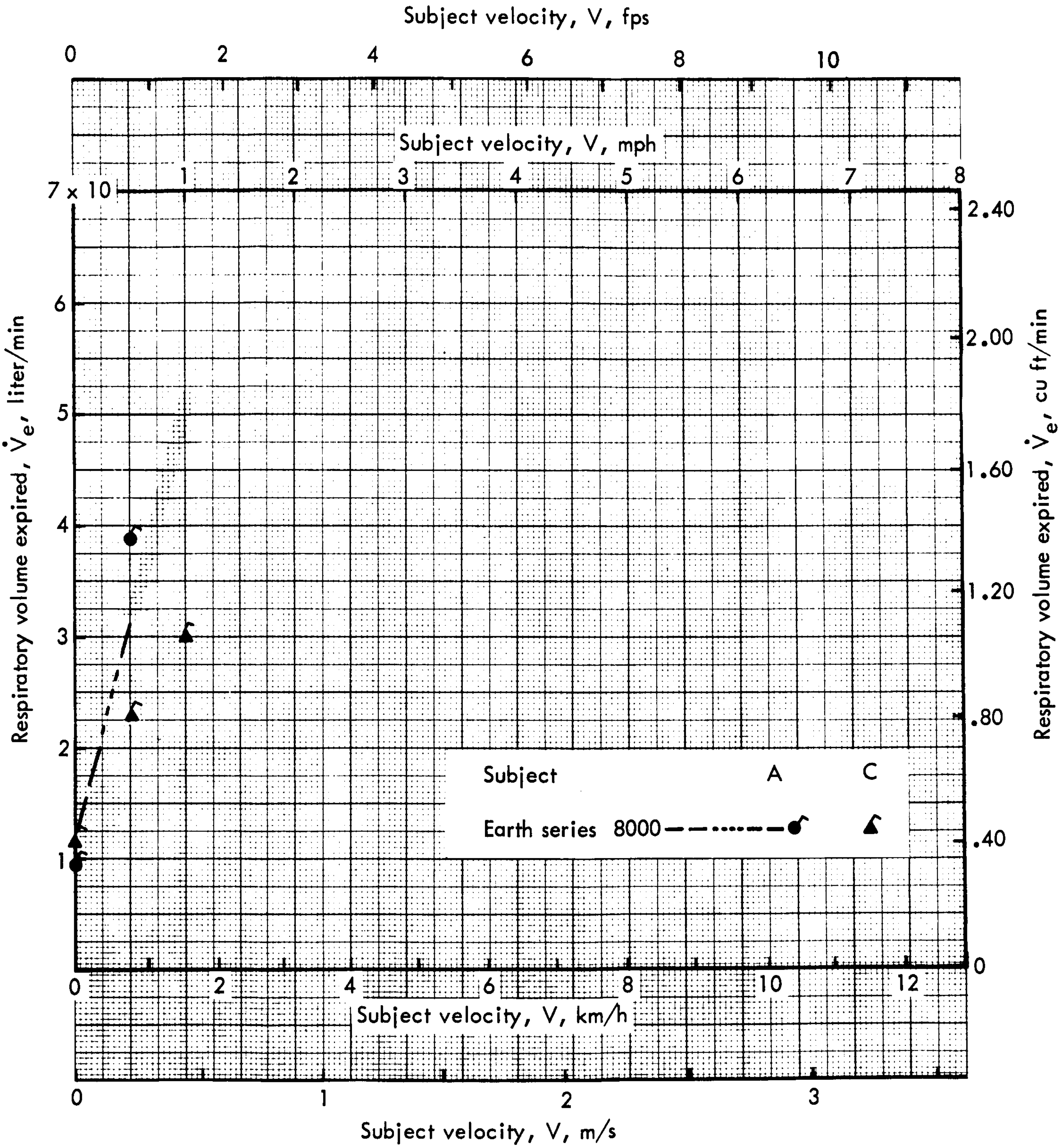


Figure 87. – Average mean respiratory volume versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

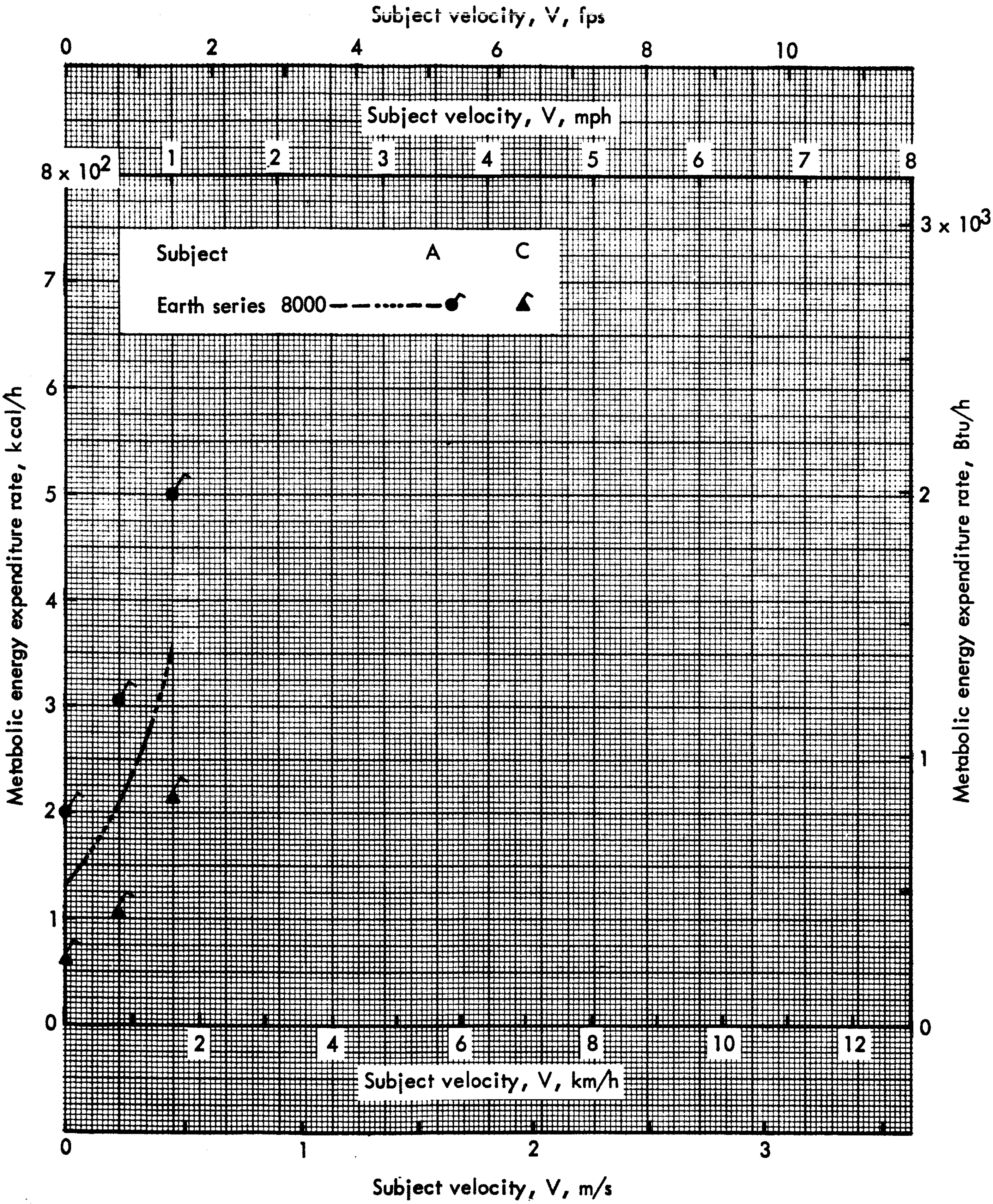


Figure 88. – Average metabolic energy expenditure rate versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

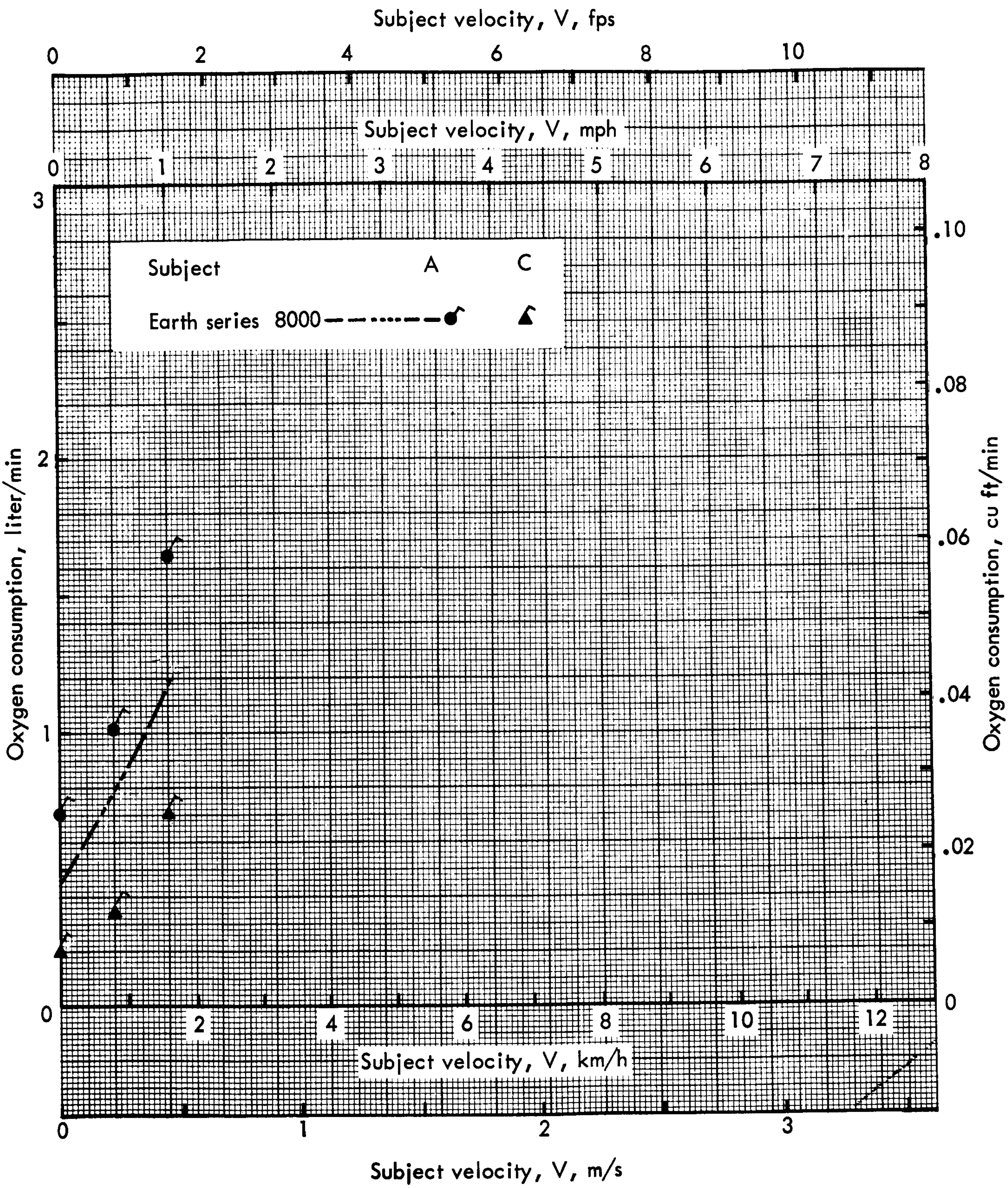


Figure 89. – Average oxygen consumption versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

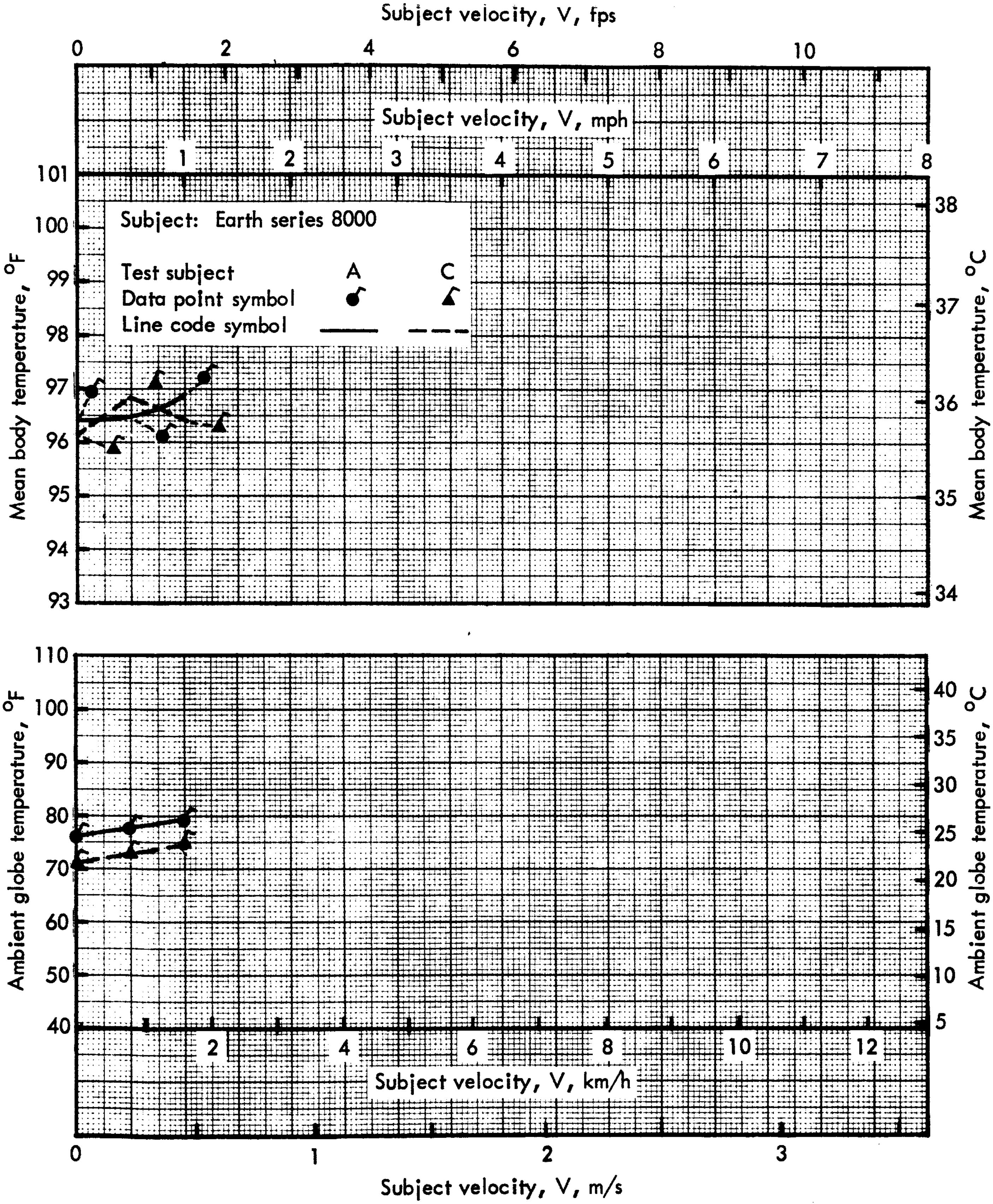


Figure 90. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

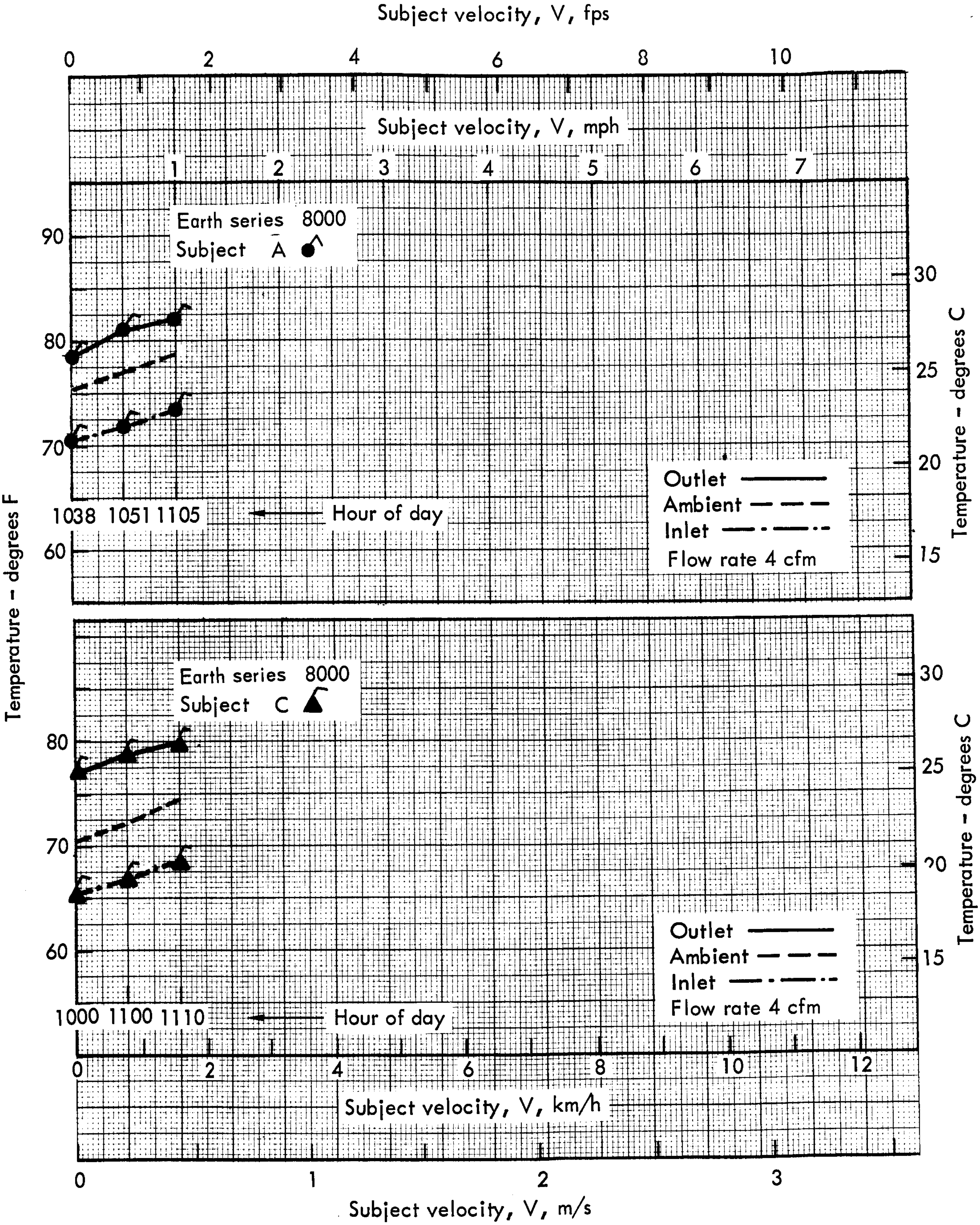


Figure 91. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, walking horizontally.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

Test Series 1020

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking and running	Work Variable	ascending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	9	5	7

Respiration, respiratory rate	Figure 92
respiratory volume expired	Figure 93
Metabolism, metabolic energy expenditure rate	Figure 94
metabolic energy expenditure rate per unit length	Figure 95
oxygen consumption	Figure 96
oxygen consumption per unit length	Figure 97
Cardiovascular function, cardiac rate	Figure 98
Body temperature, mean body temperature	Figure 99
Pressure suit environmental data	Not Obtained

Comments:

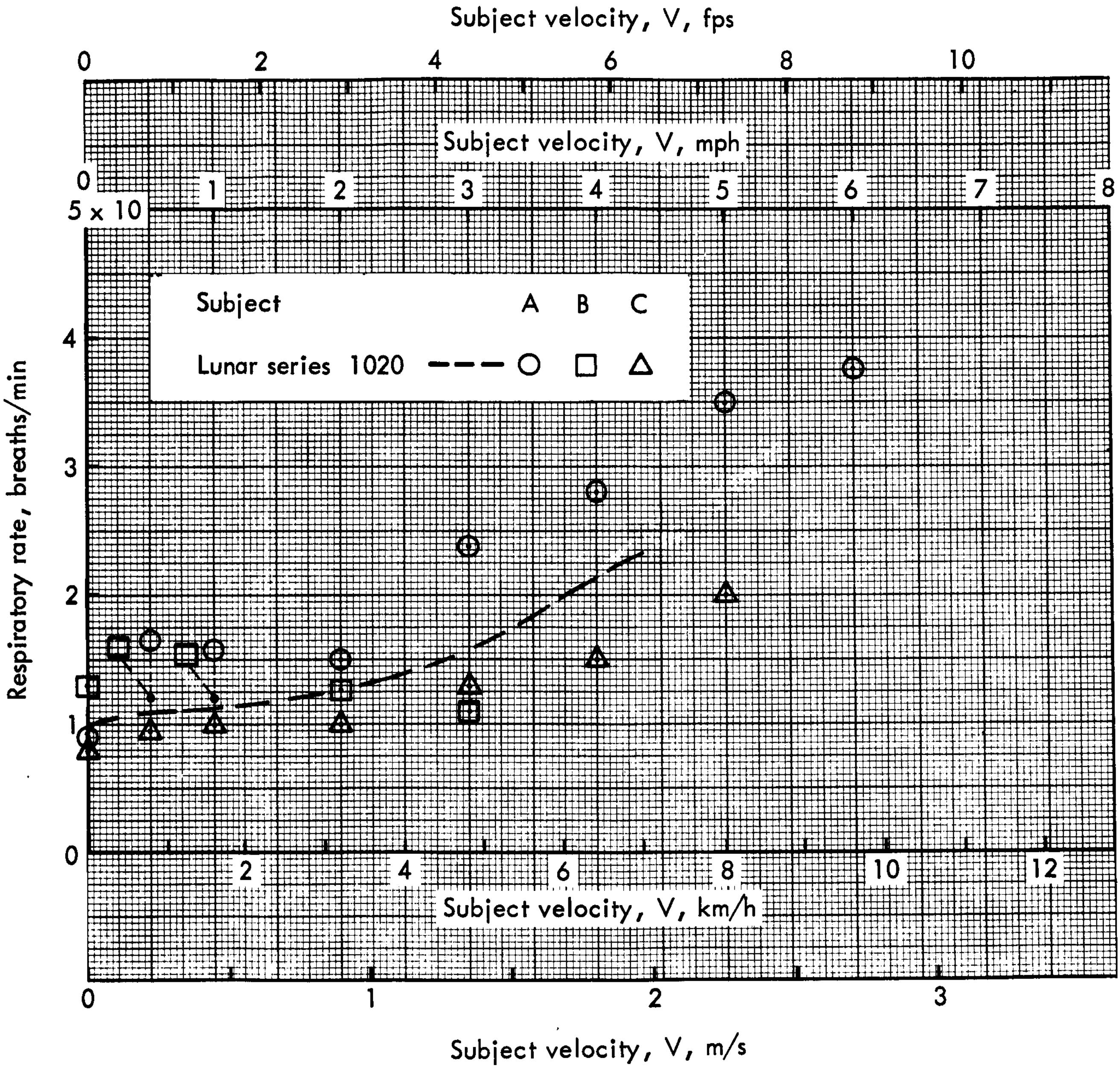


Figure 92. – Average respiratory rate versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

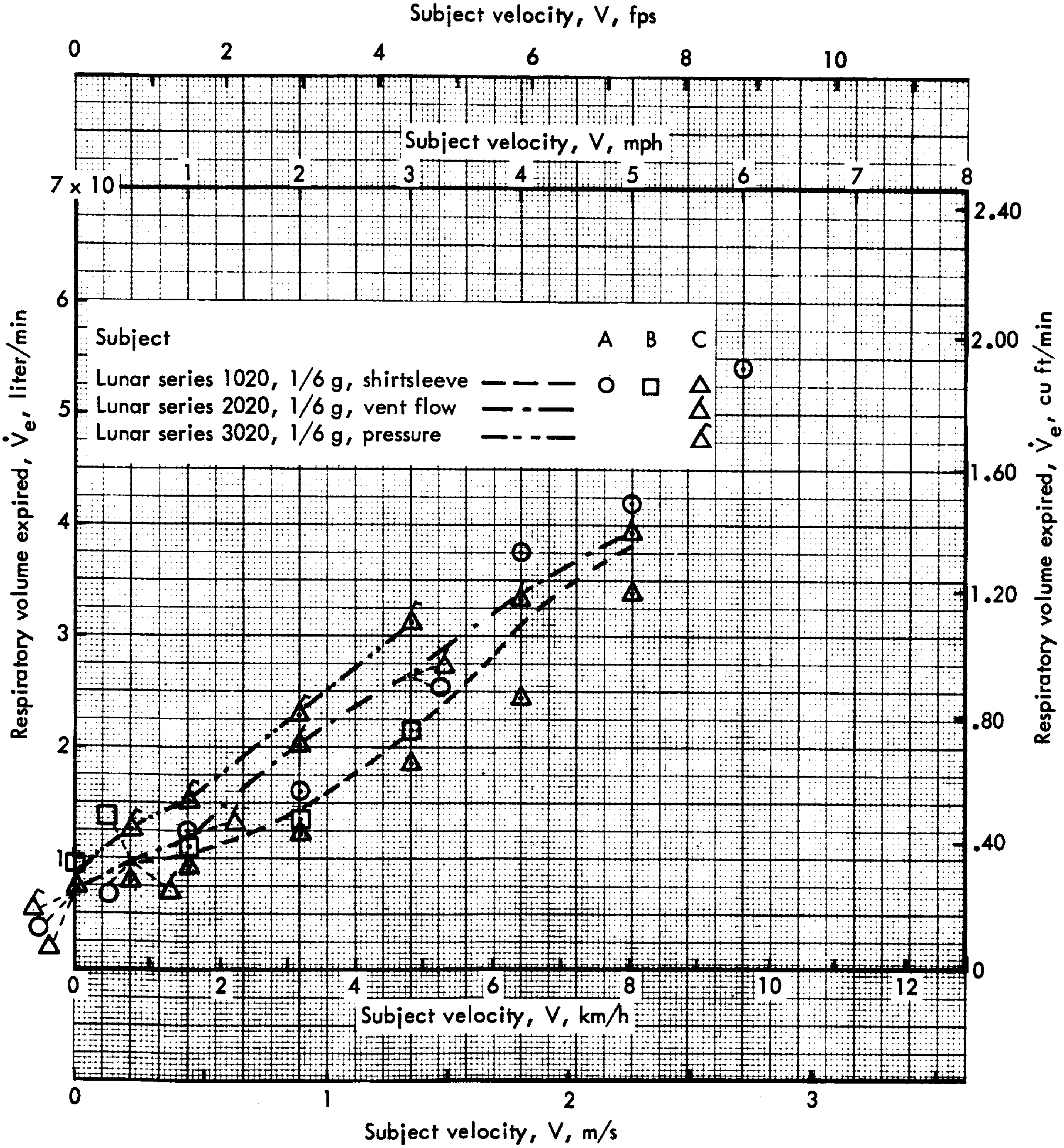


Figure 93. – Average mean respiratory volume versus subject velocity ascending at 10 degrees walking and running.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

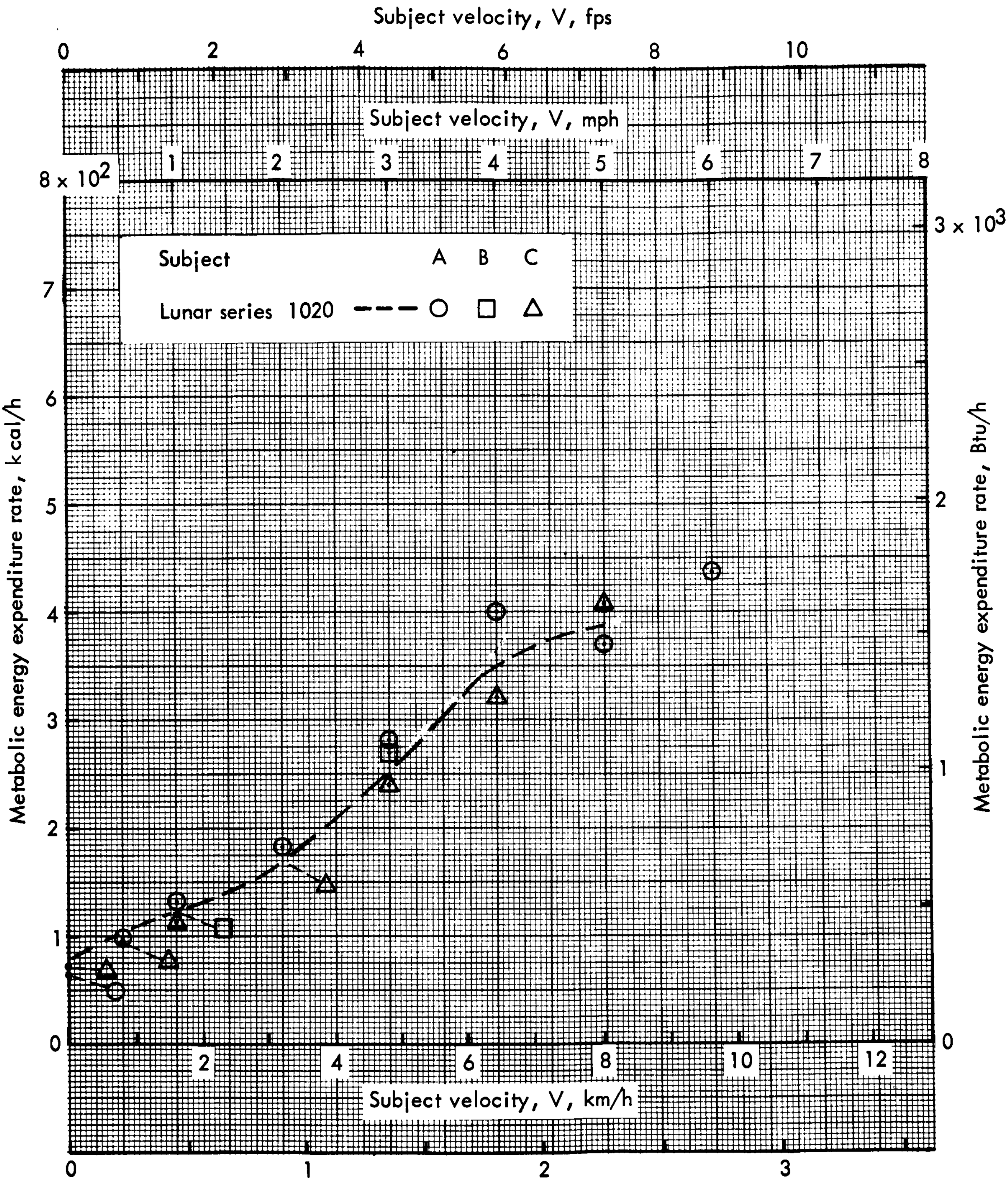


Figure 94. – Average metabolic energy expenditure rate versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g shirtsleeve, susp. gear, pack I

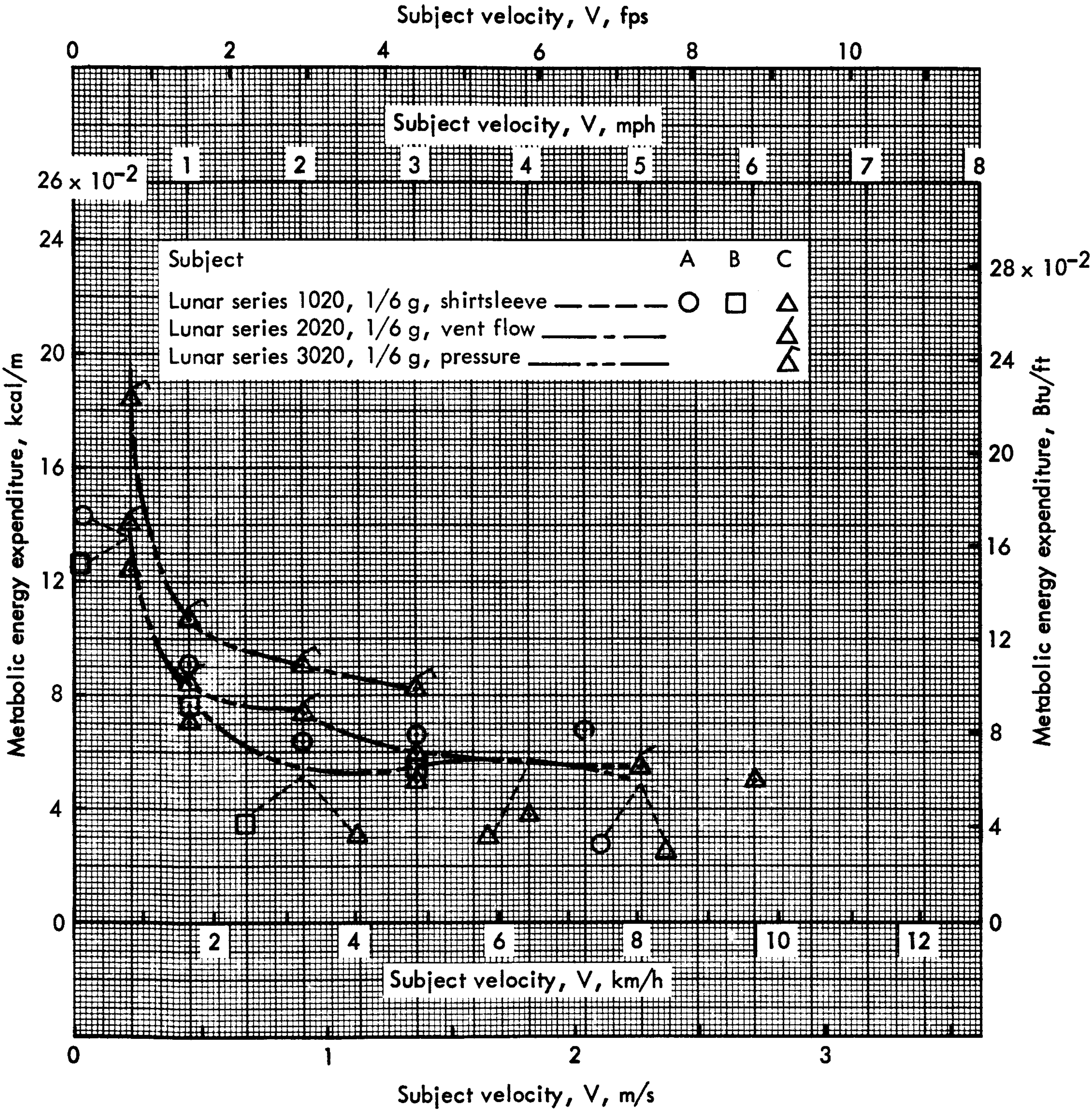


Figure 95. – Average metabolic energy expenditure per unit length versus subject velocity ascending at 10 degrees walking and running. Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

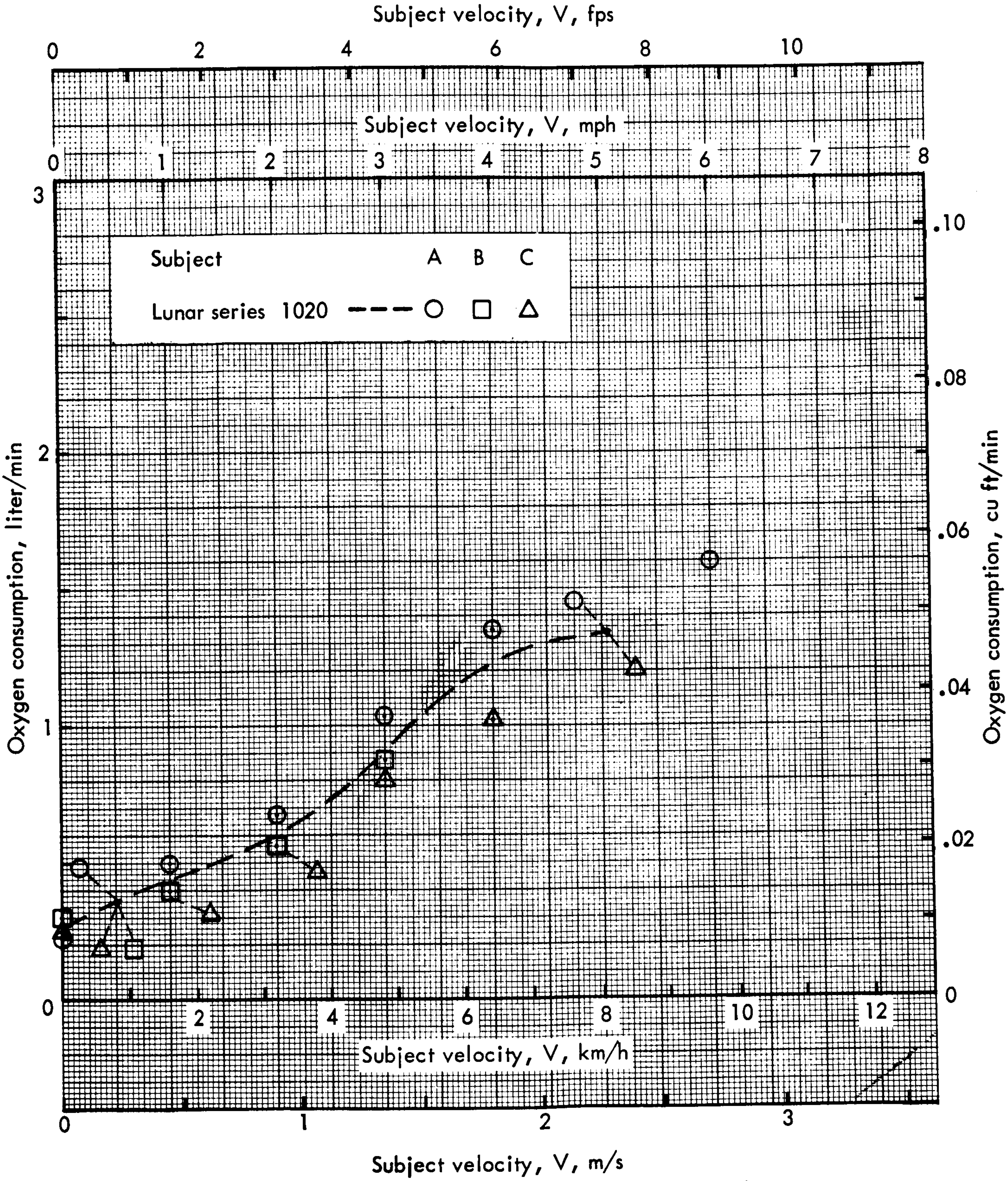


Figure 96. – Average oxygen consumption versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

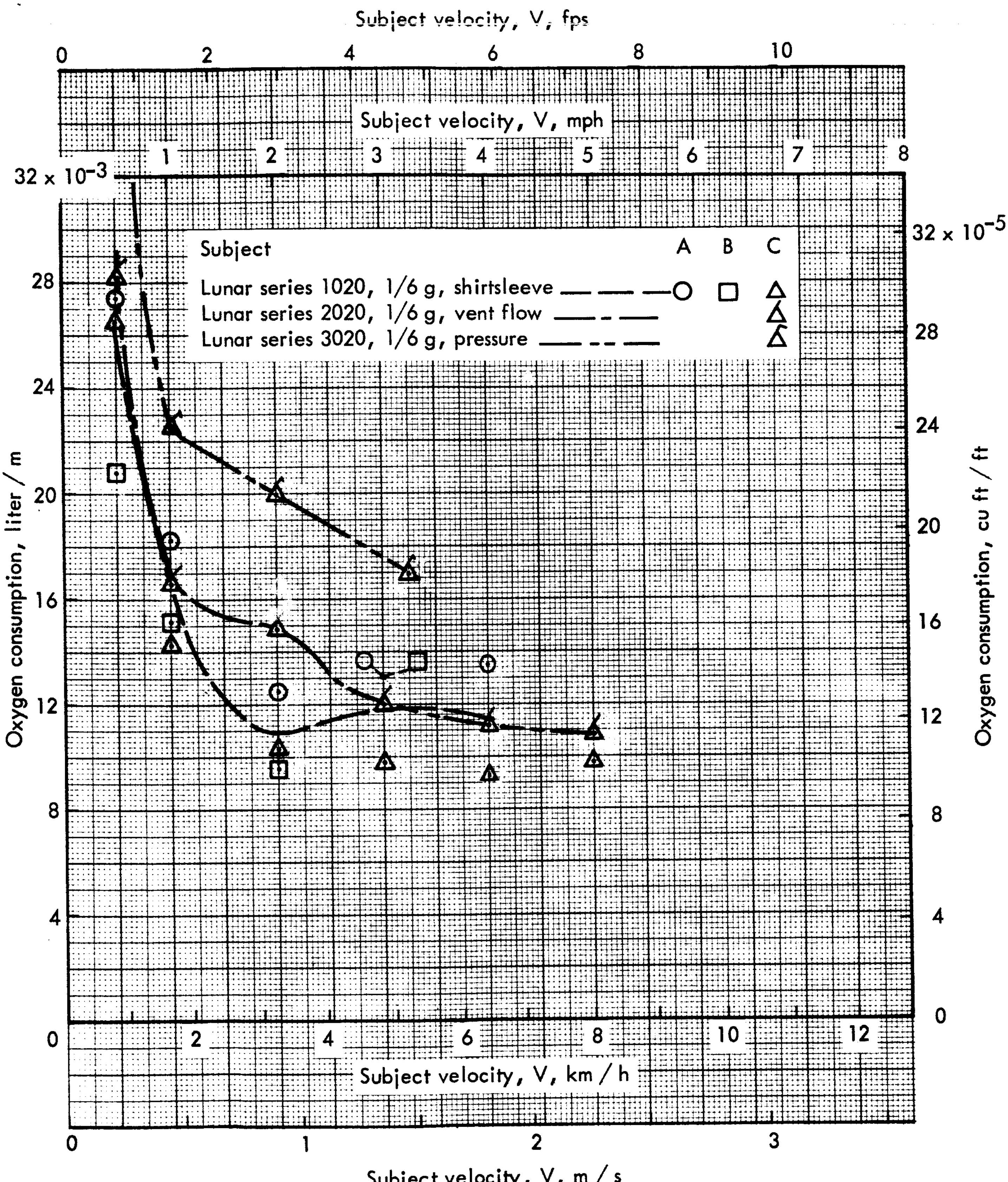


Figure 97. – Average oxygen consumption per unit length versus subject velocity ascending at 10 degrees walking and running.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

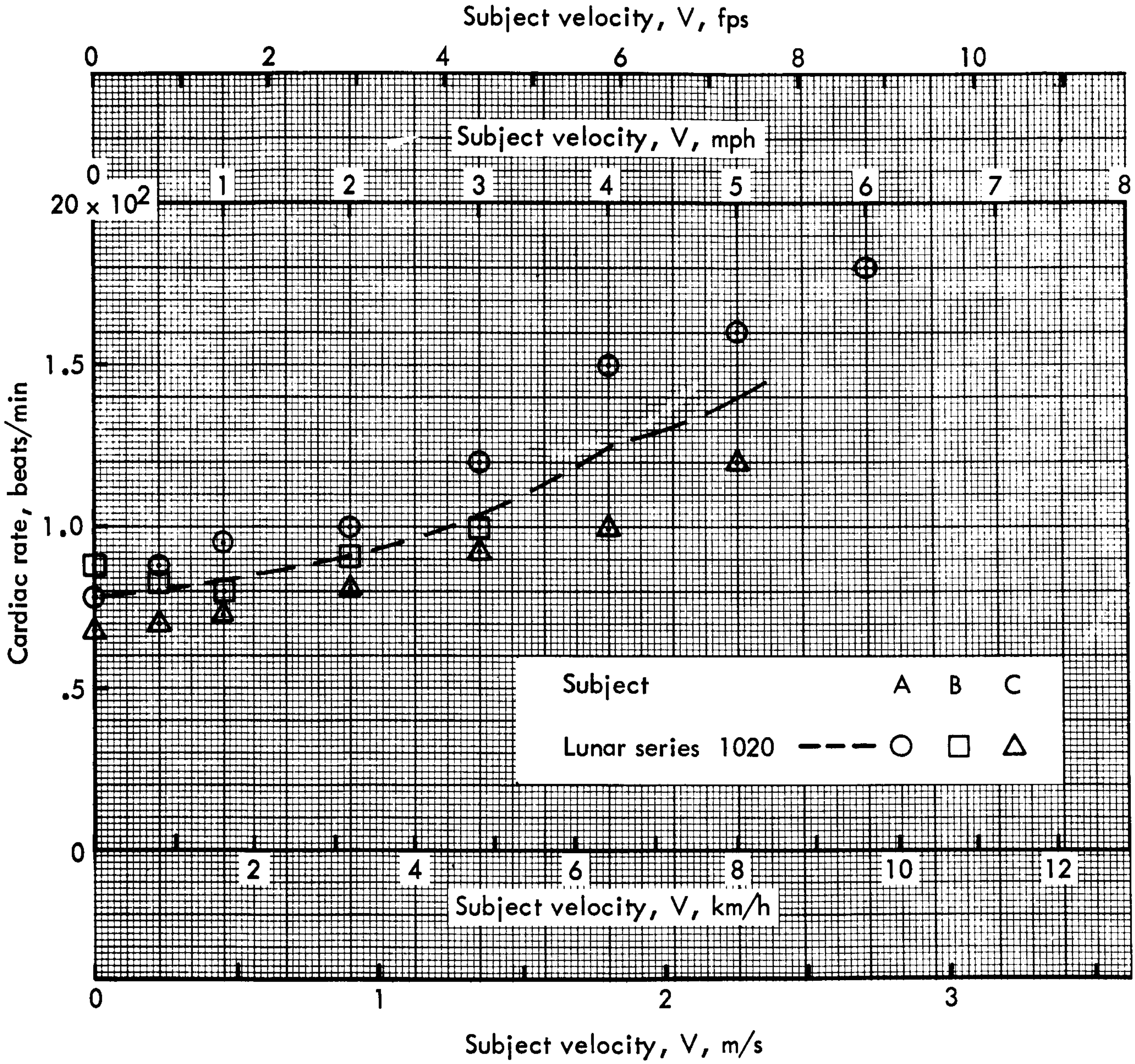


Figure 98. – Average cardiac rate versus subject velocity ascending at 10 degrees walking and running.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

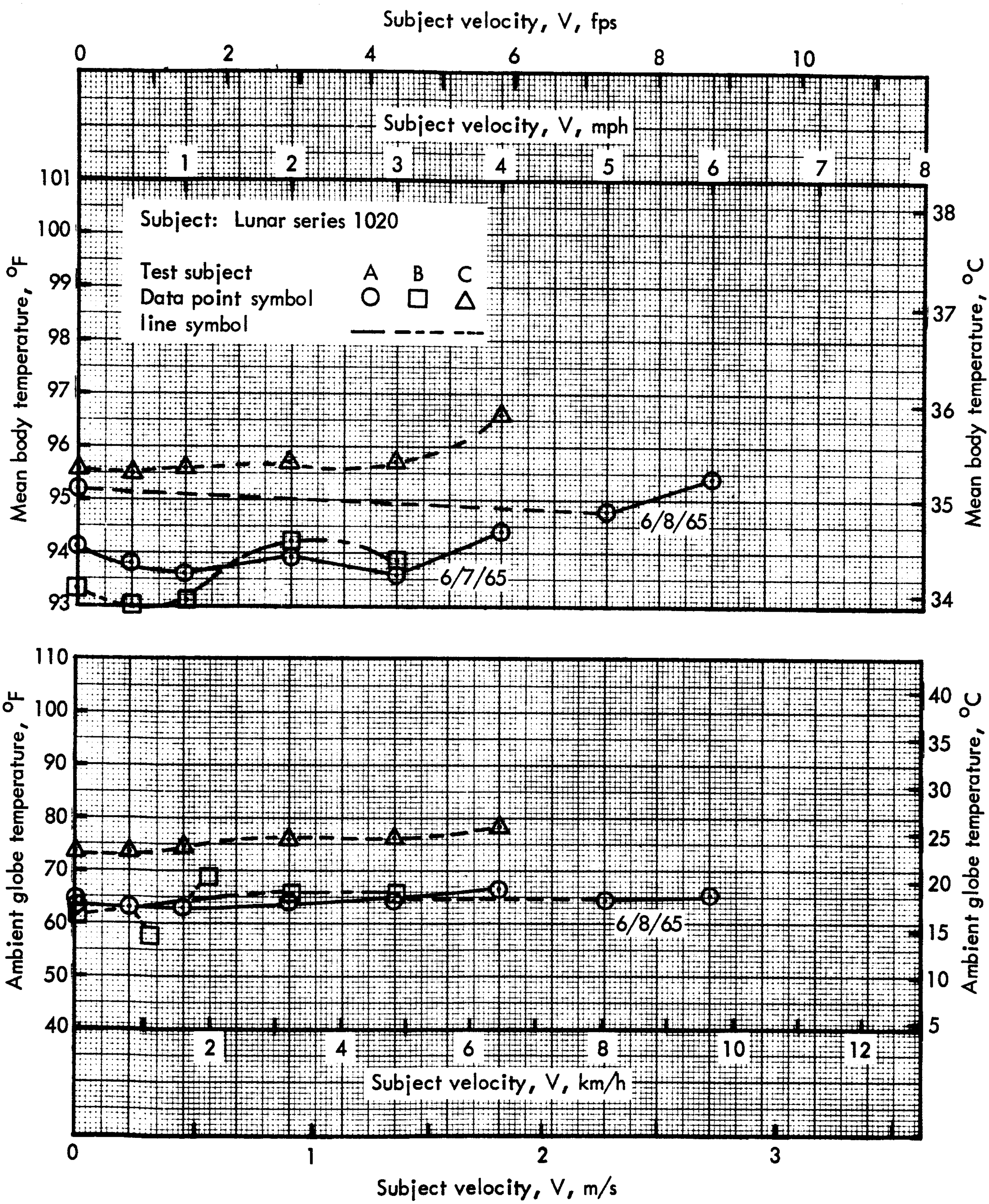


Figure 99. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2020

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	walking and running	Work Variable	ascending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			7

Respiration,	respiratory rate	Figure 100 *
	respiratory volume expired	Figure 93
Metabolism,	metabolic energy expenditure rate	Figure 101
	metabolic energy expenditure rate per unit length	Figure 95
	oxygen consumption	Figure 102 *
	oxygen consumption per unit length	Figure 97
Cardiovascular function, cardiac rate		Figure 103
Body temperature, mean body temperature		Figure 104
Pressure suit environmental data		Figure 105

Comments:

*Figures 100 and 102 were modified according to intermediate averages

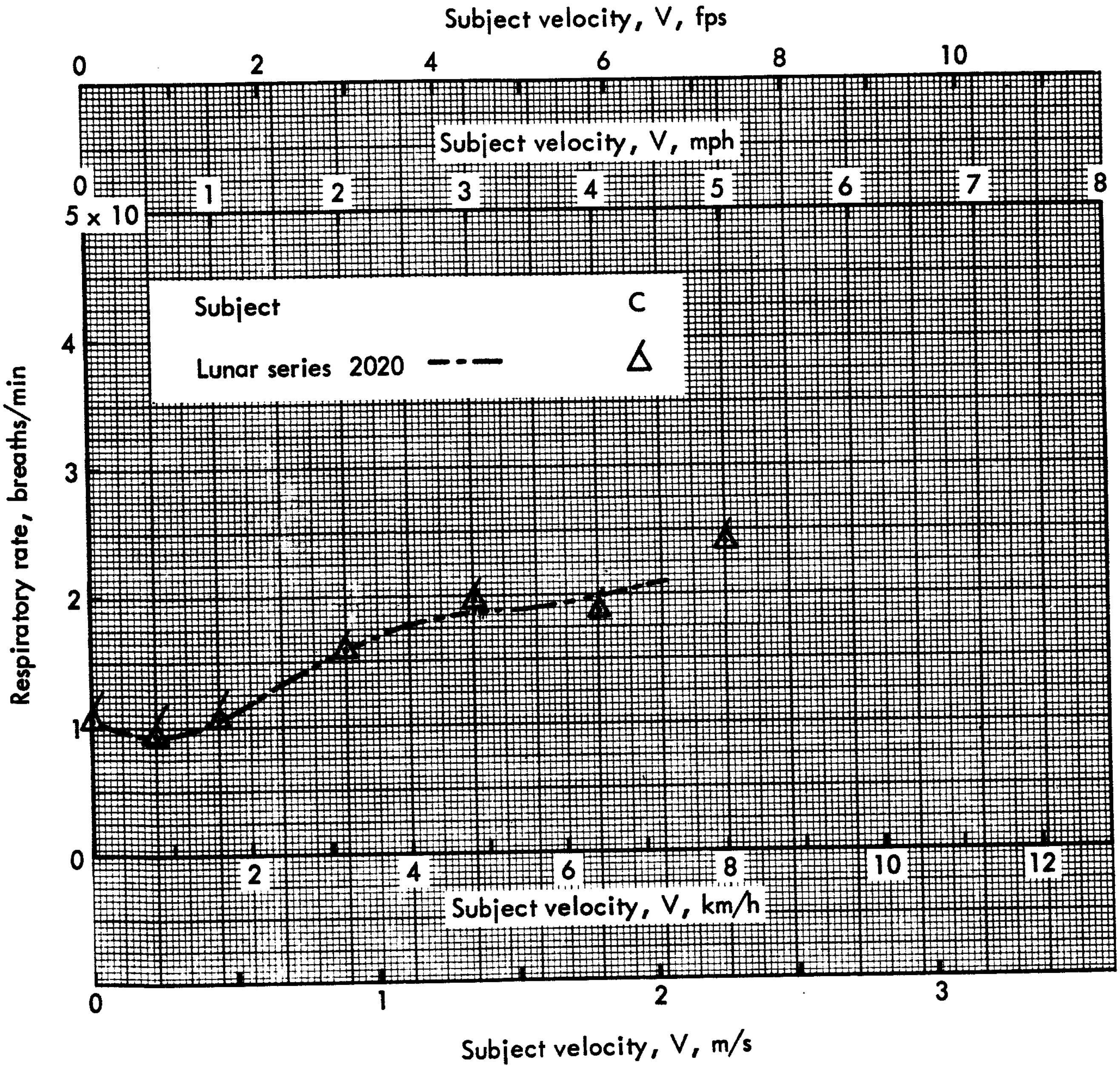


Figure 100. – Respiratory rate versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

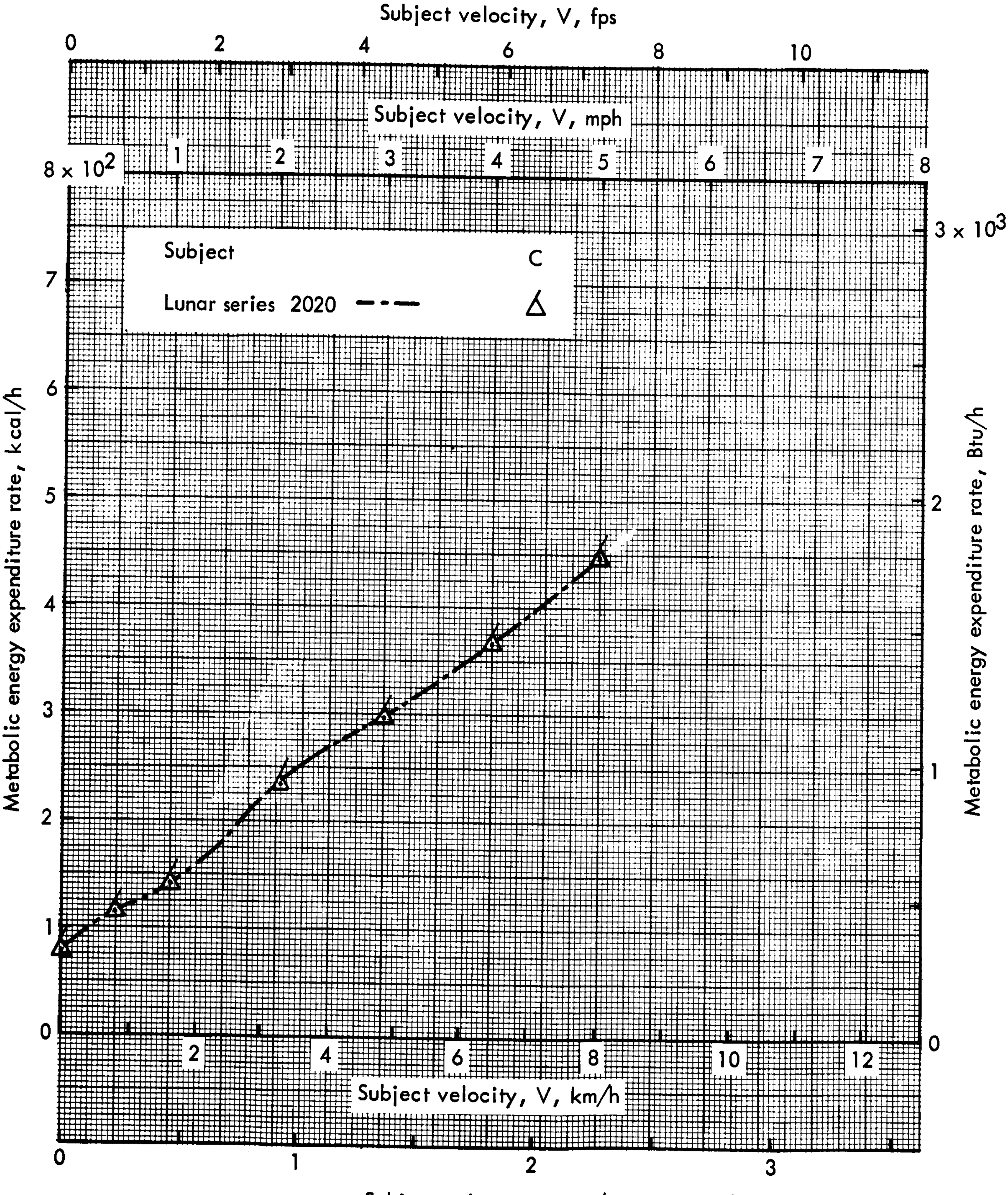


Figure 101. – Metabolic energy expenditure rate versus subject velocity in ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

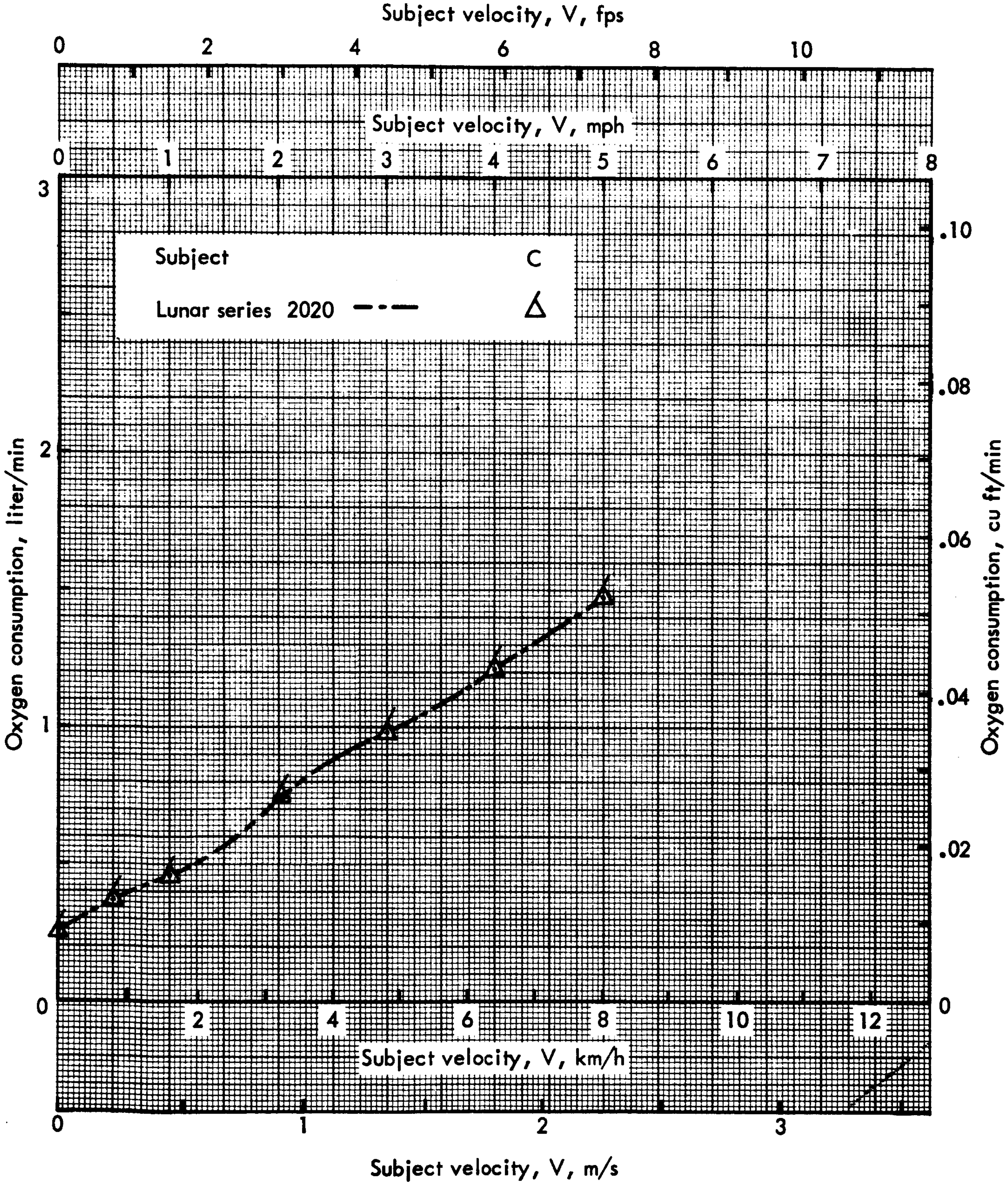


Figure 102. – Oxygen consumption versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

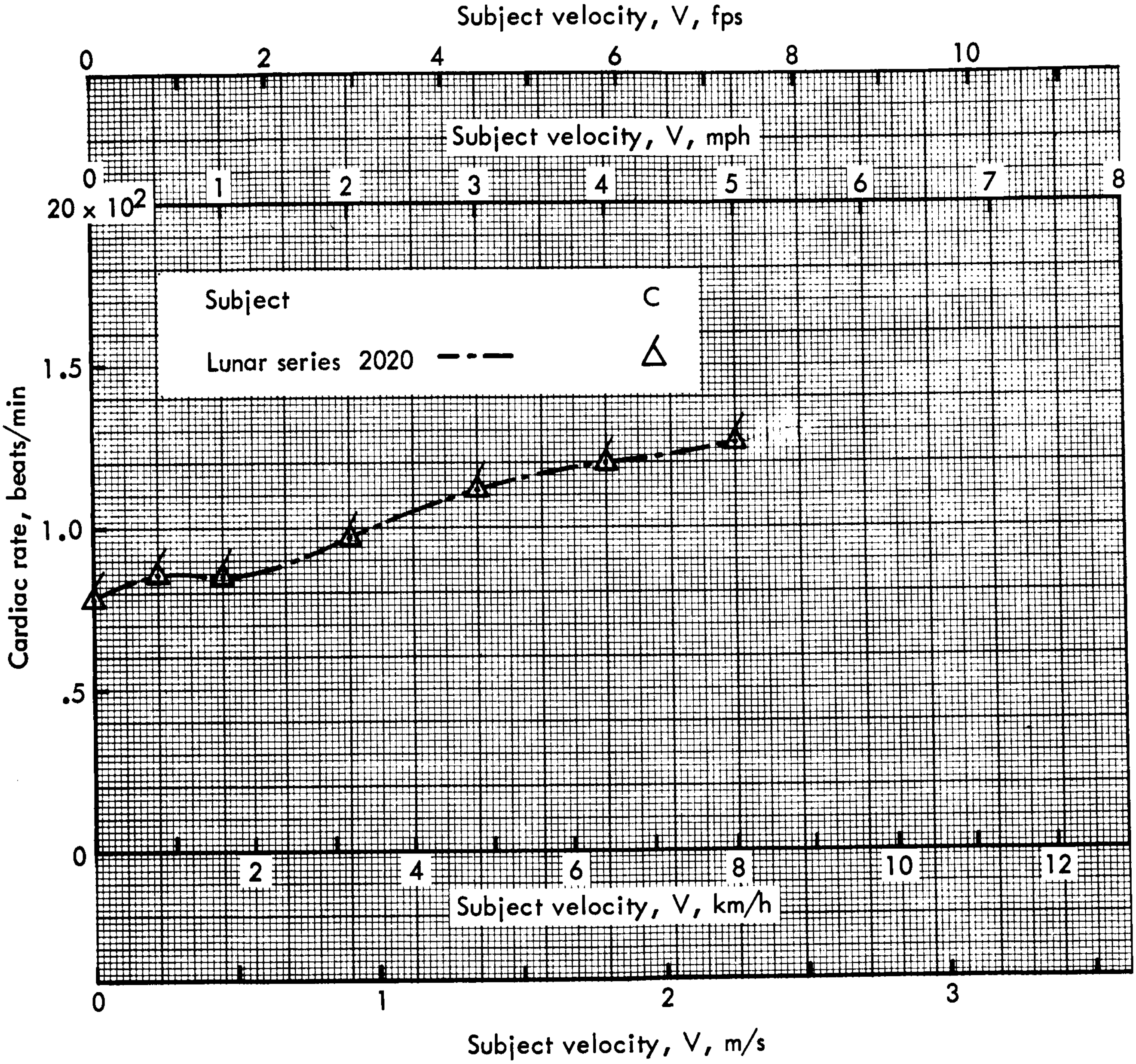


Figure 103. – Cardiac rate versus subject velocity ascending at 10 degrees walking and running.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

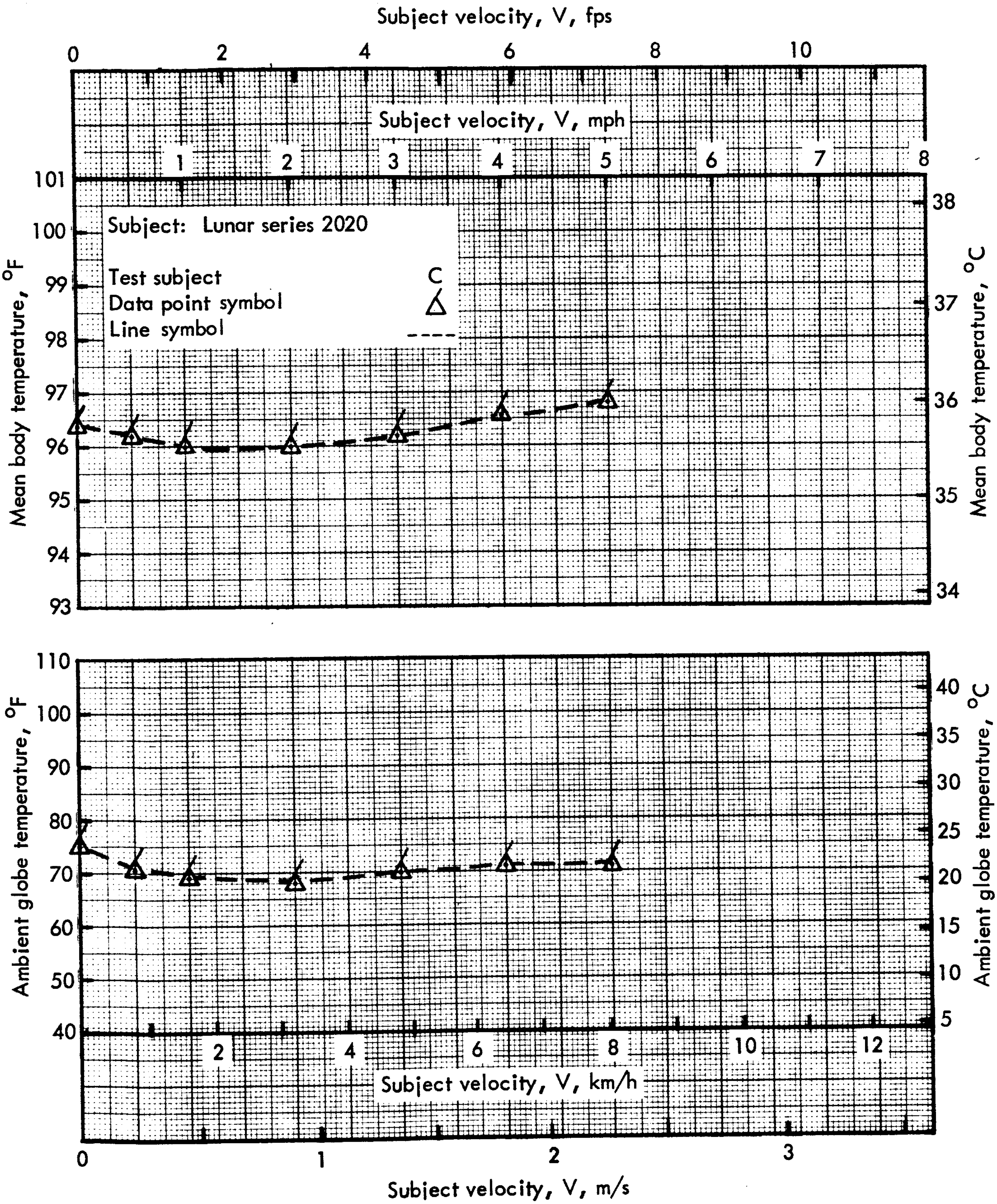


Figure 104. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

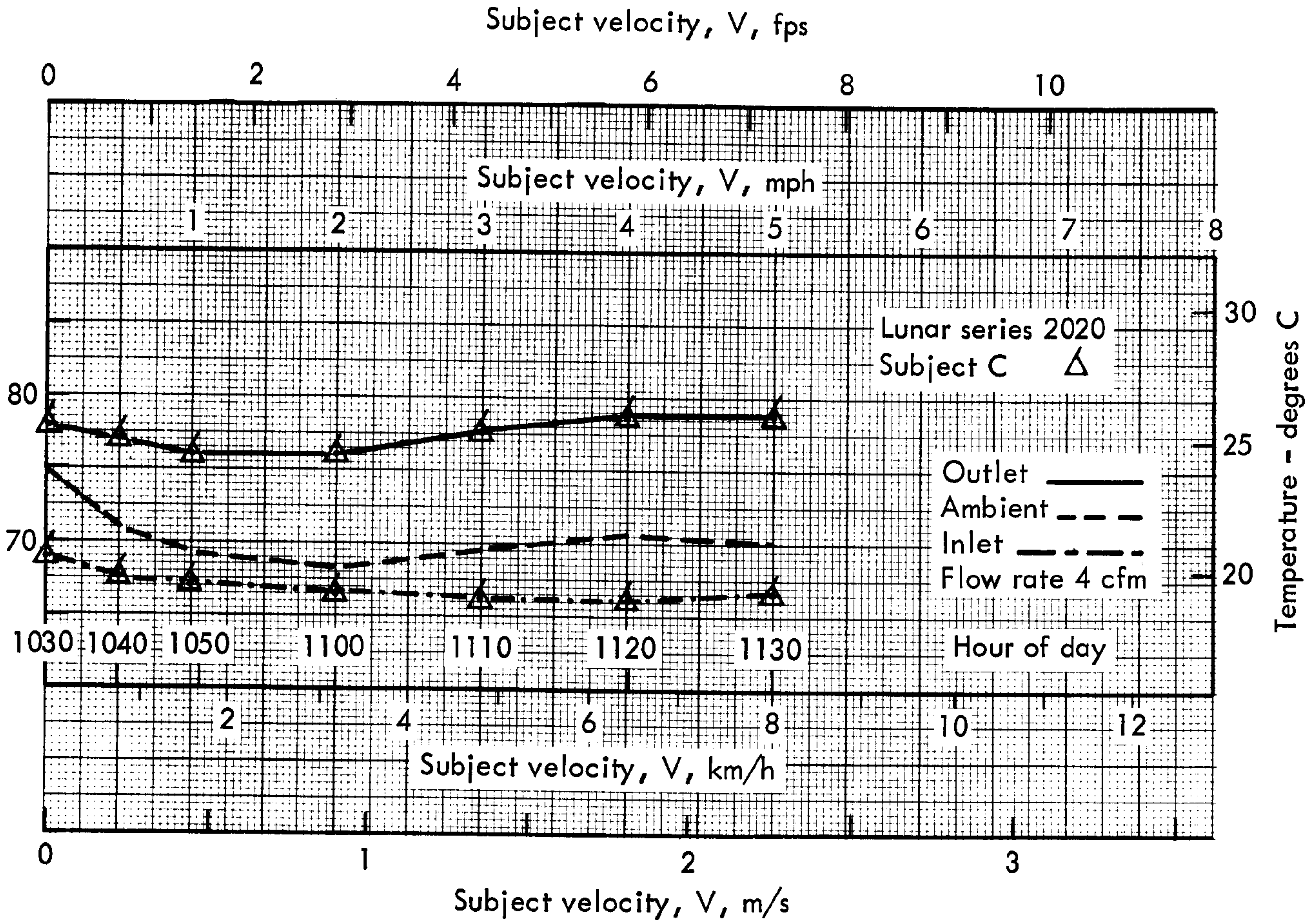


Figure 105. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3020

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	ascending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			5

Respiration,	respiratory rate	Figure 106 *
	respiratory volume expired	Figure 93
Metabolism,	metabolic energy expenditure rate	Figure 107
	metabolic energy expenditure rate per unit length	Figure 95
	oxygen consumption	Figure 108 *
	oxygen consumption per unit length	Figure 97
Cardiovascular function, cardiac rate		Figure 109
Body temperature, mean body temperature		Figure 110
Pressure suit environmental data		Figure 111

Comments:

*Figures 106 thru 108 were modified according to intermediate averages

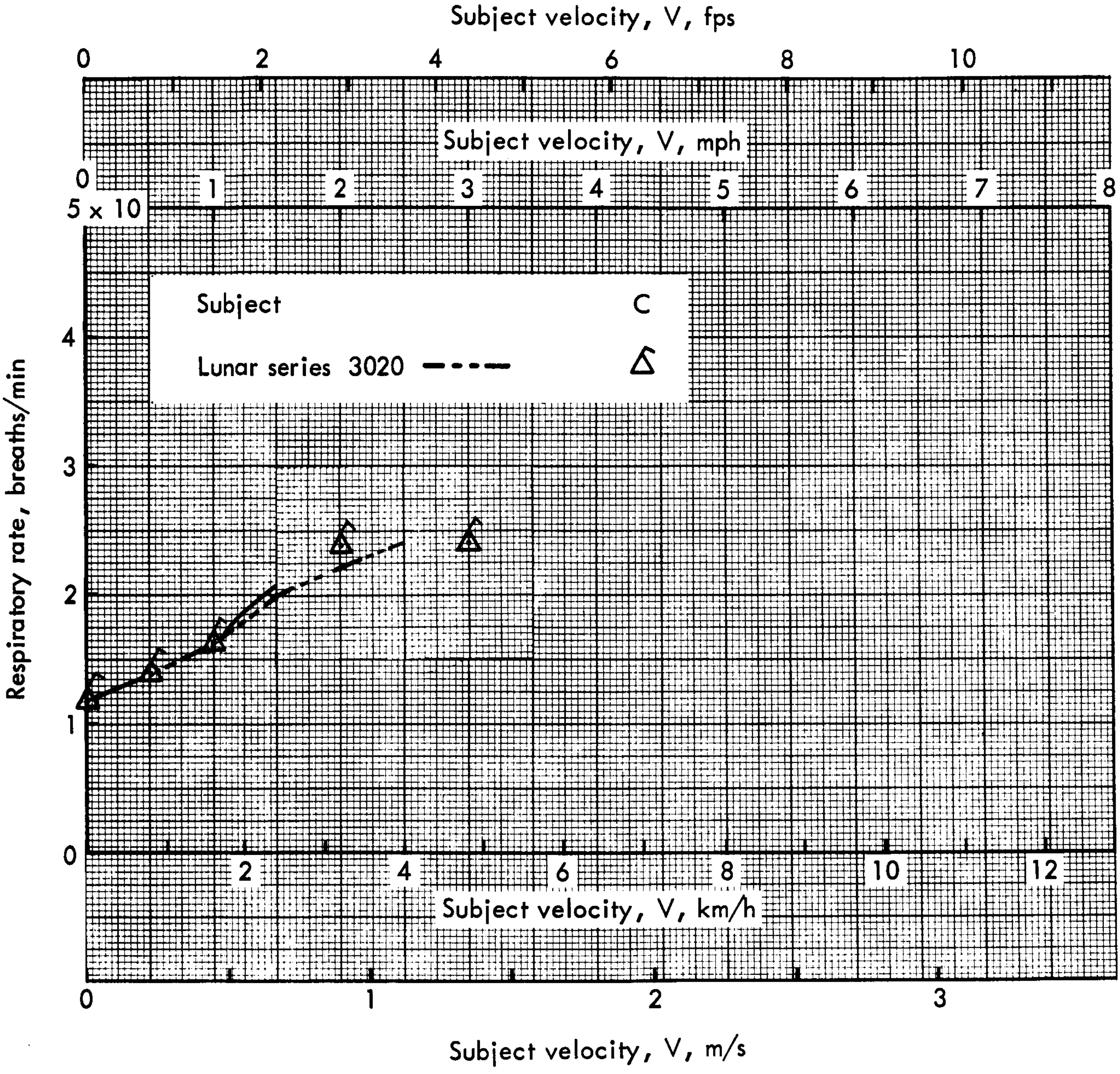


Figure 106. – Respiratory rate versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

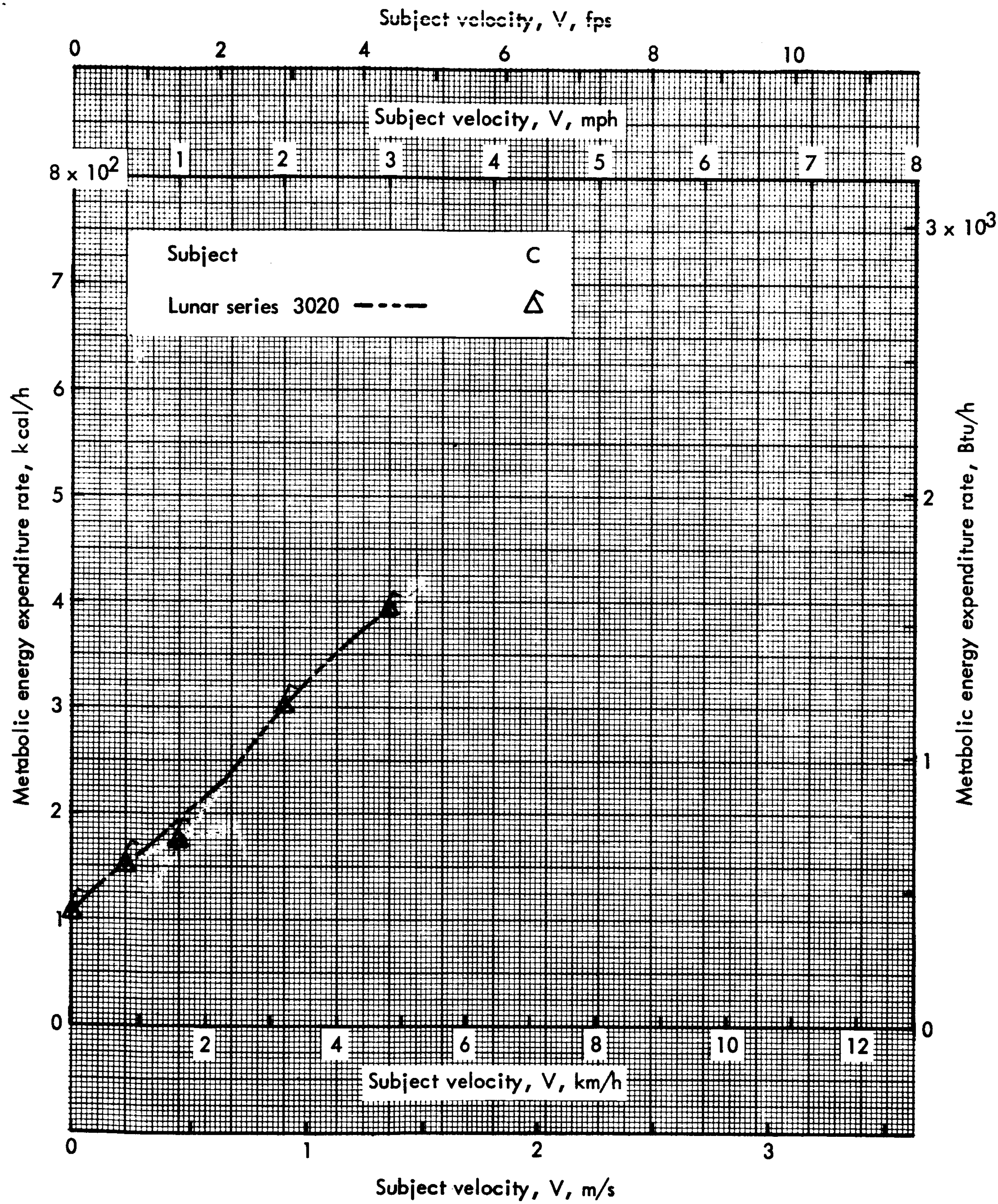


Figure 107. – Average metabolic energy expenditure rate versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

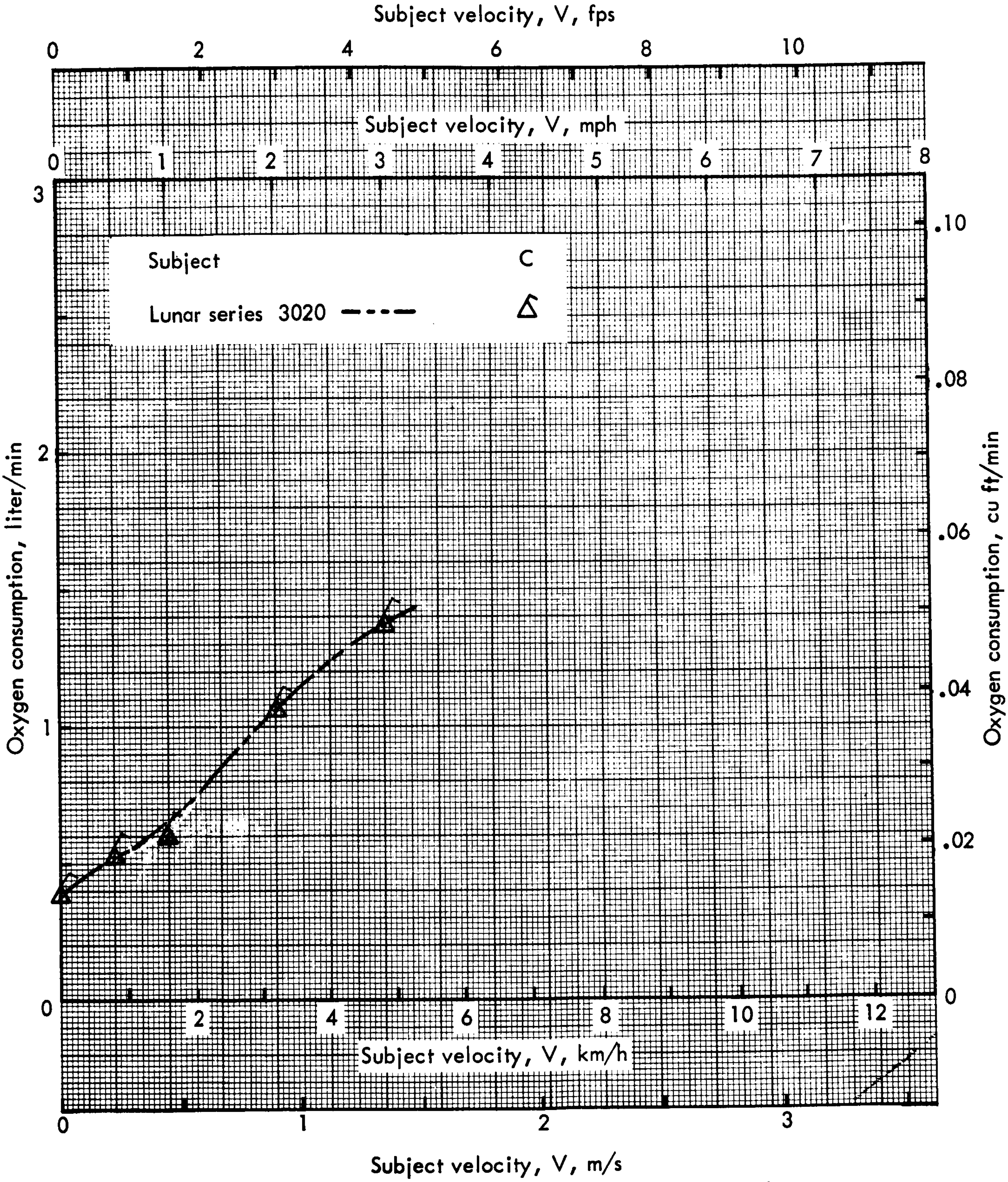


Figure 108. – Oxygen consumption versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

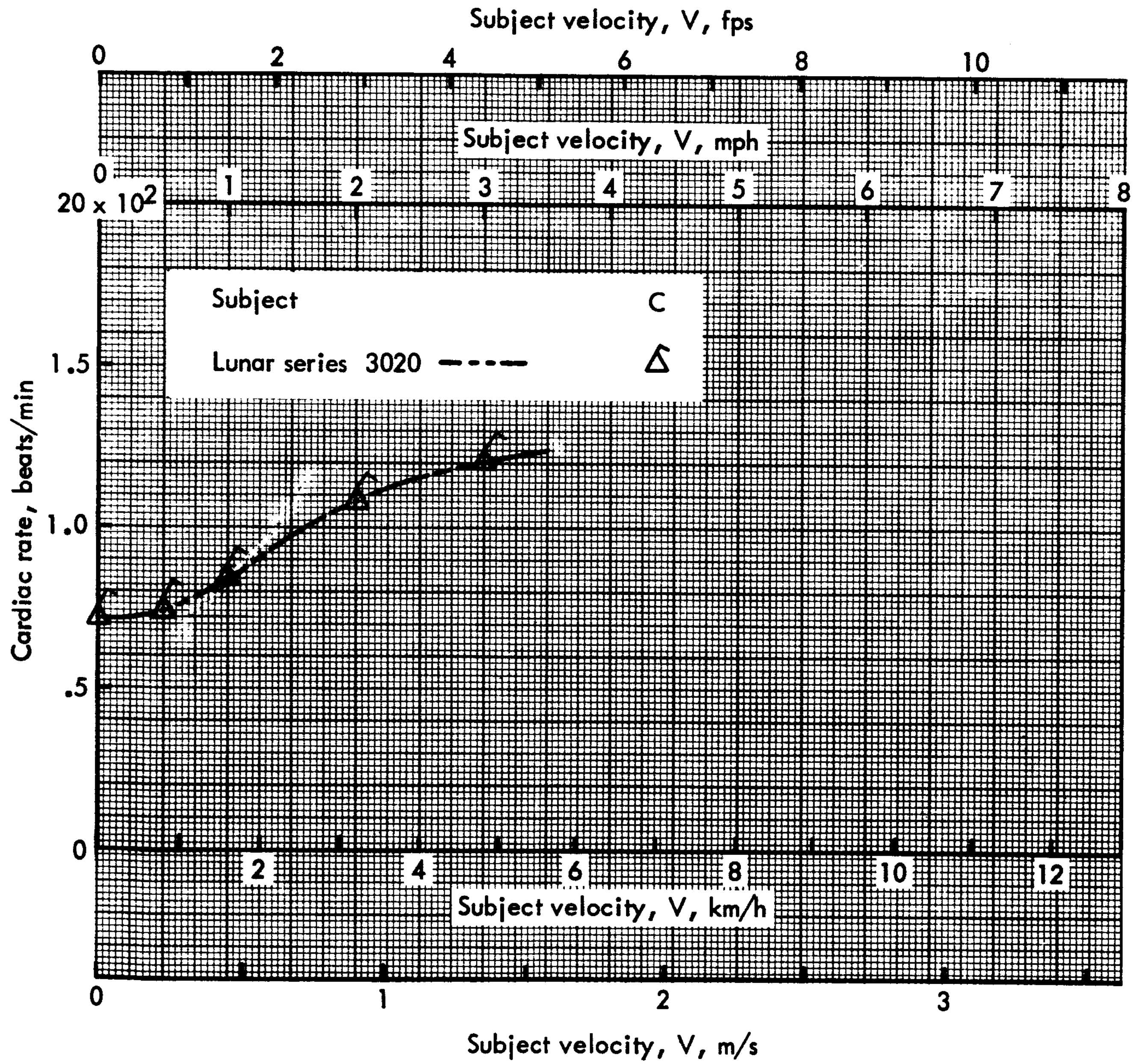


Figure 109. – Cardiac rate versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

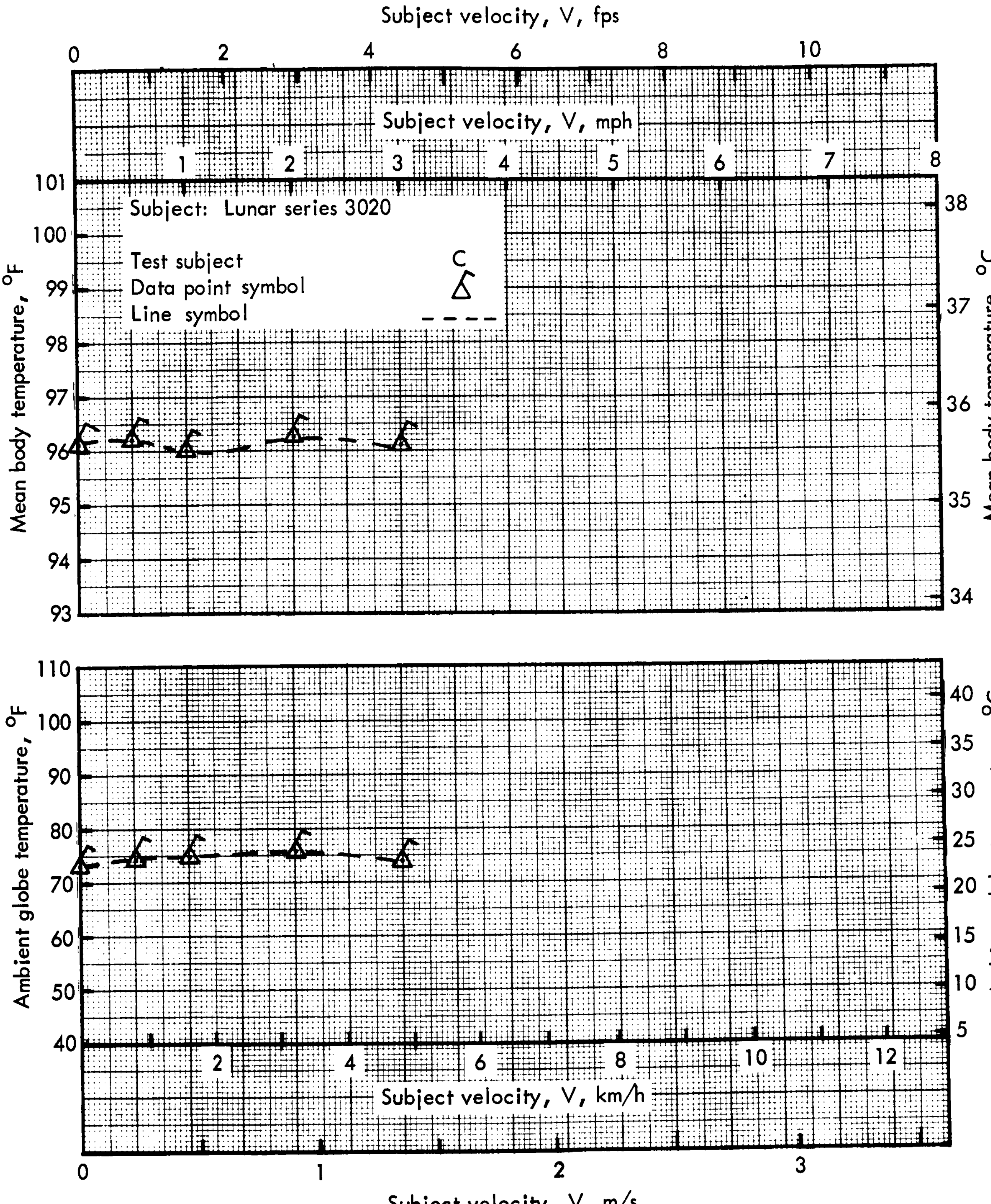


Figure 110. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

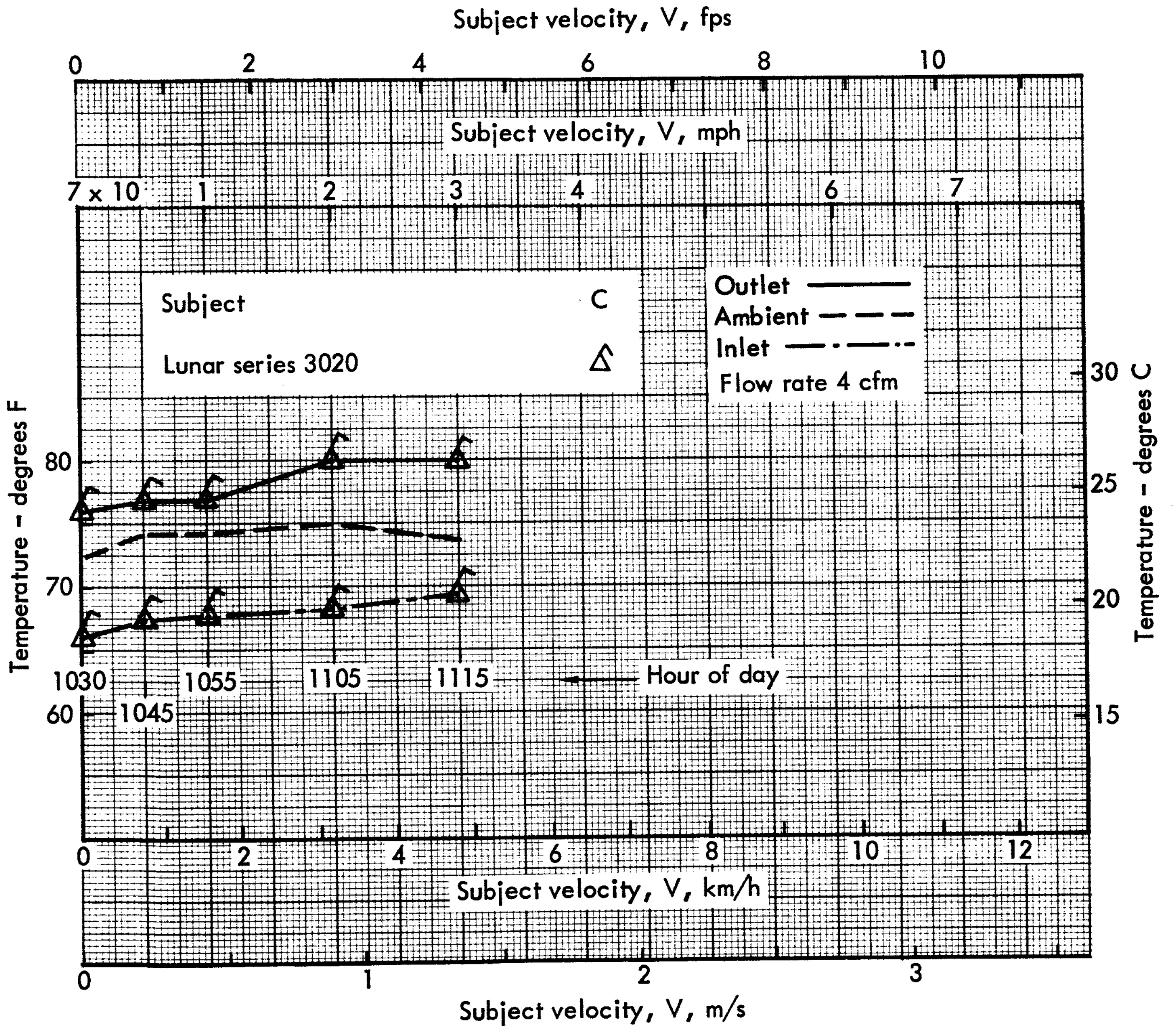


Figure 111. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity ascending at 10 degrees walking and running.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series	6020

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking	Work Variable	ascending at 10°
Gravity: Lunar		Earth	x

Test Location:

1/6 g Treadmill		One g Treadmill	x

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	4		11

Respiration, respiratory rate	Figure 112
respiratory volume expired	Figure 113*
Metabolism, metabolic energy expenditure rate	Figure 114
metabolic energy expenditure rate per unit length	Not Obtained
oxygen consumption	Figure 115
oxygen consumption per unit length	Not Obtained
Cardiovascular function, cardiac rate	Figure 116
Body temperature, mean body temperature	Figure 117
Pressure suit environmental data	Not Obtained

Comments:

*The respiratory volume expired by Subject A was not obtained at .5 mph

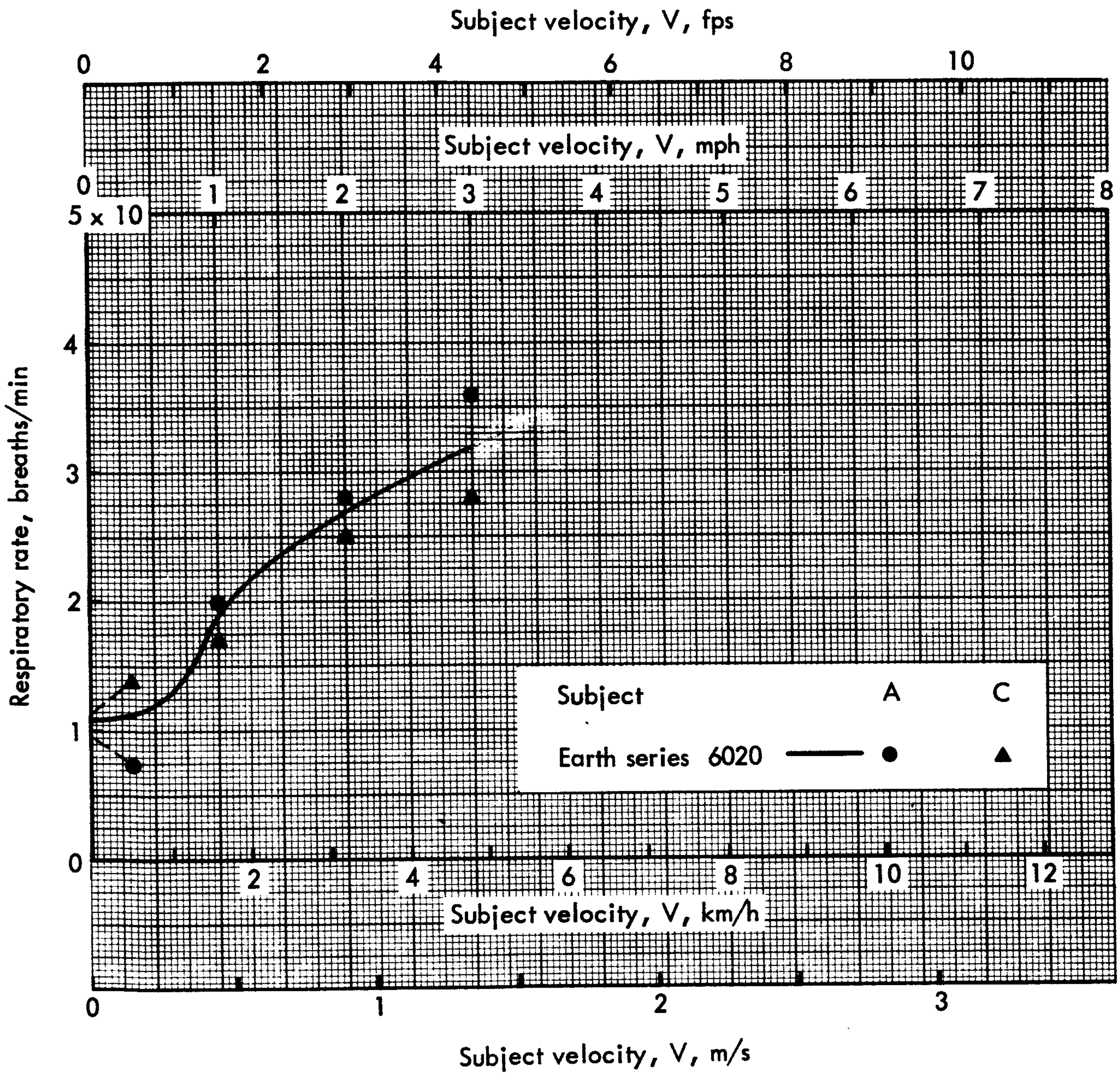


Figure 112. – Average respiratory rate versus subject velocity ascending at 10 degrees walking.
Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

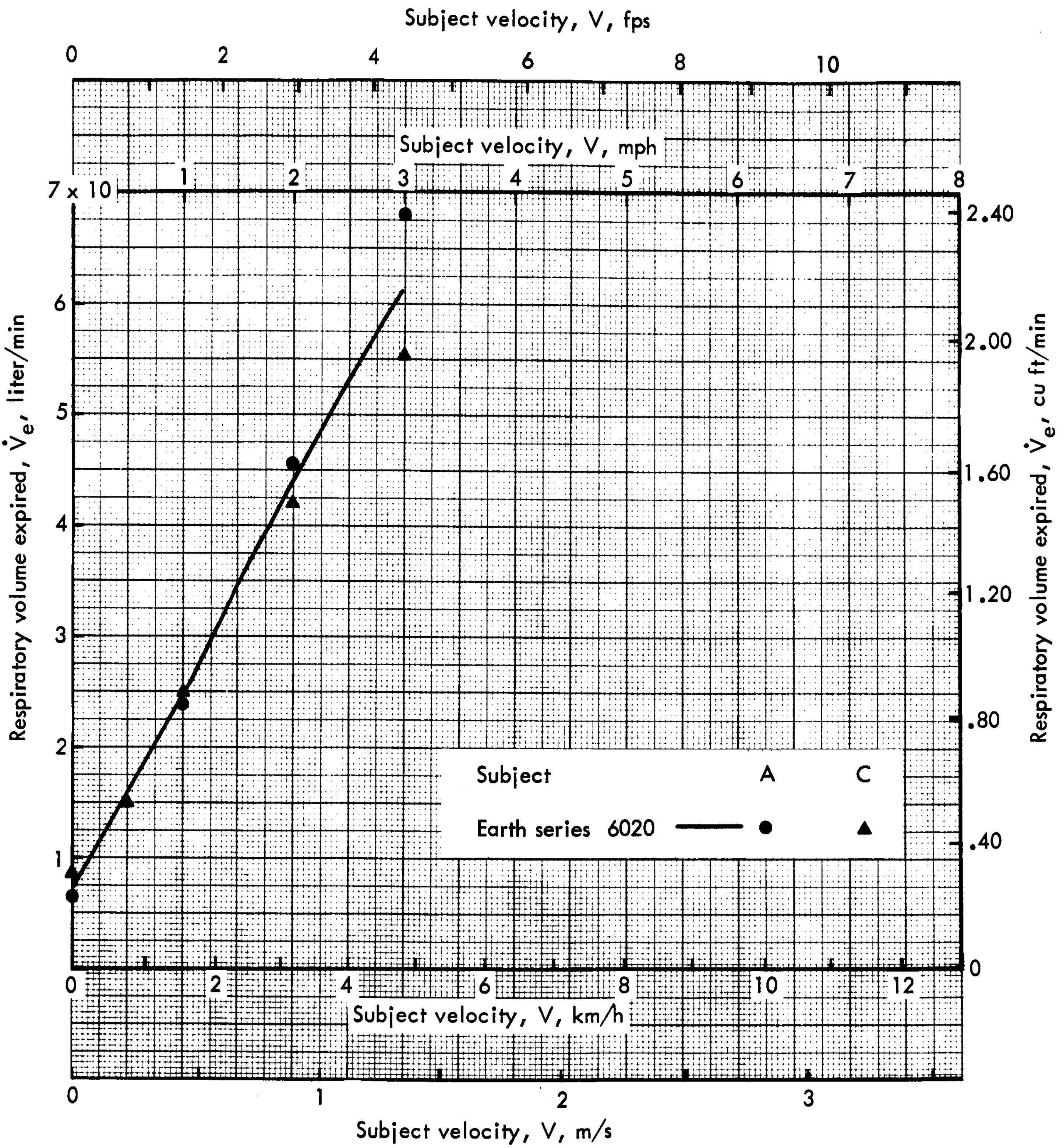


Figure 113. – Average mean respiratory volume versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

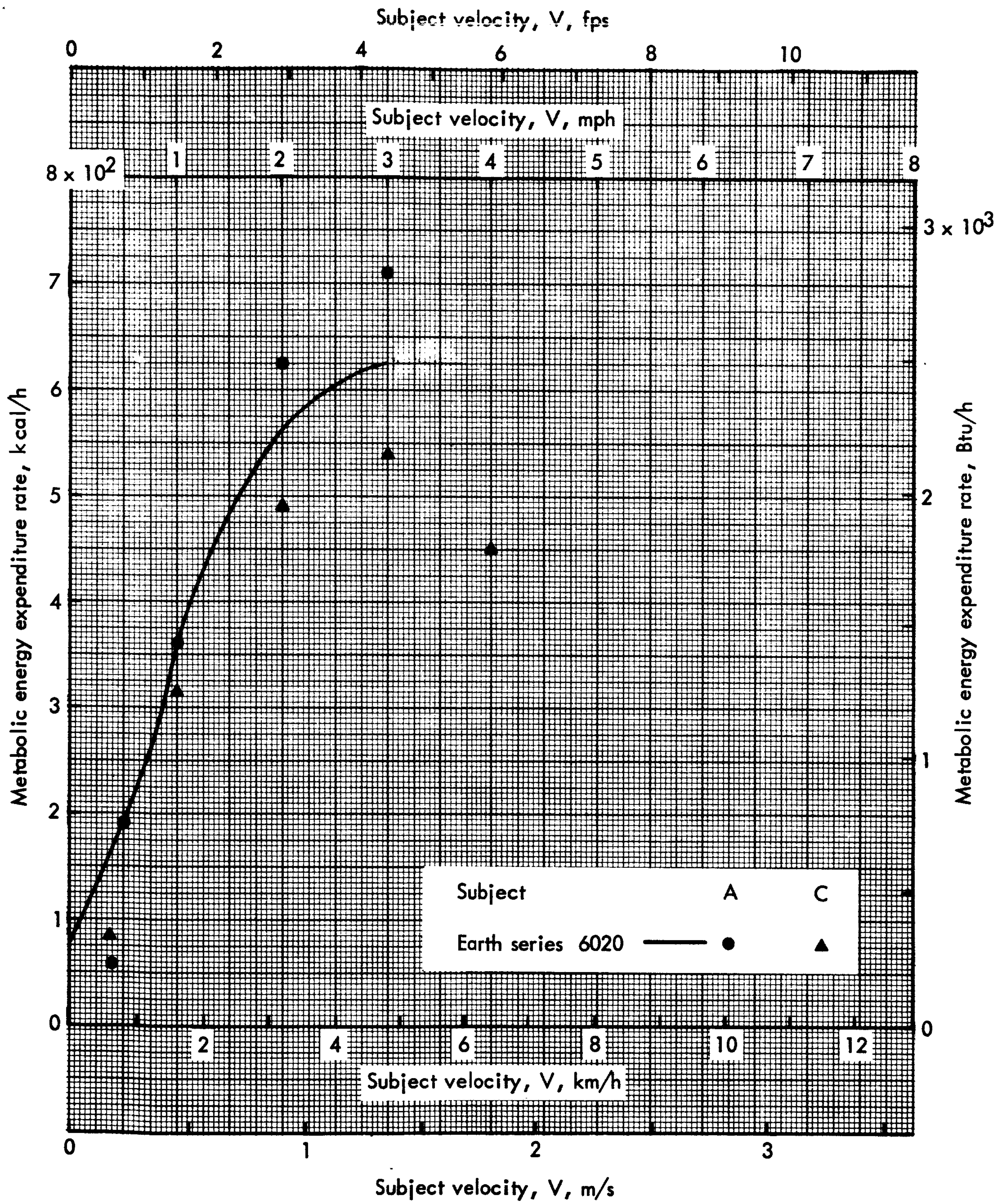


Figure 114. – Average metabolic energy expenditure rate versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

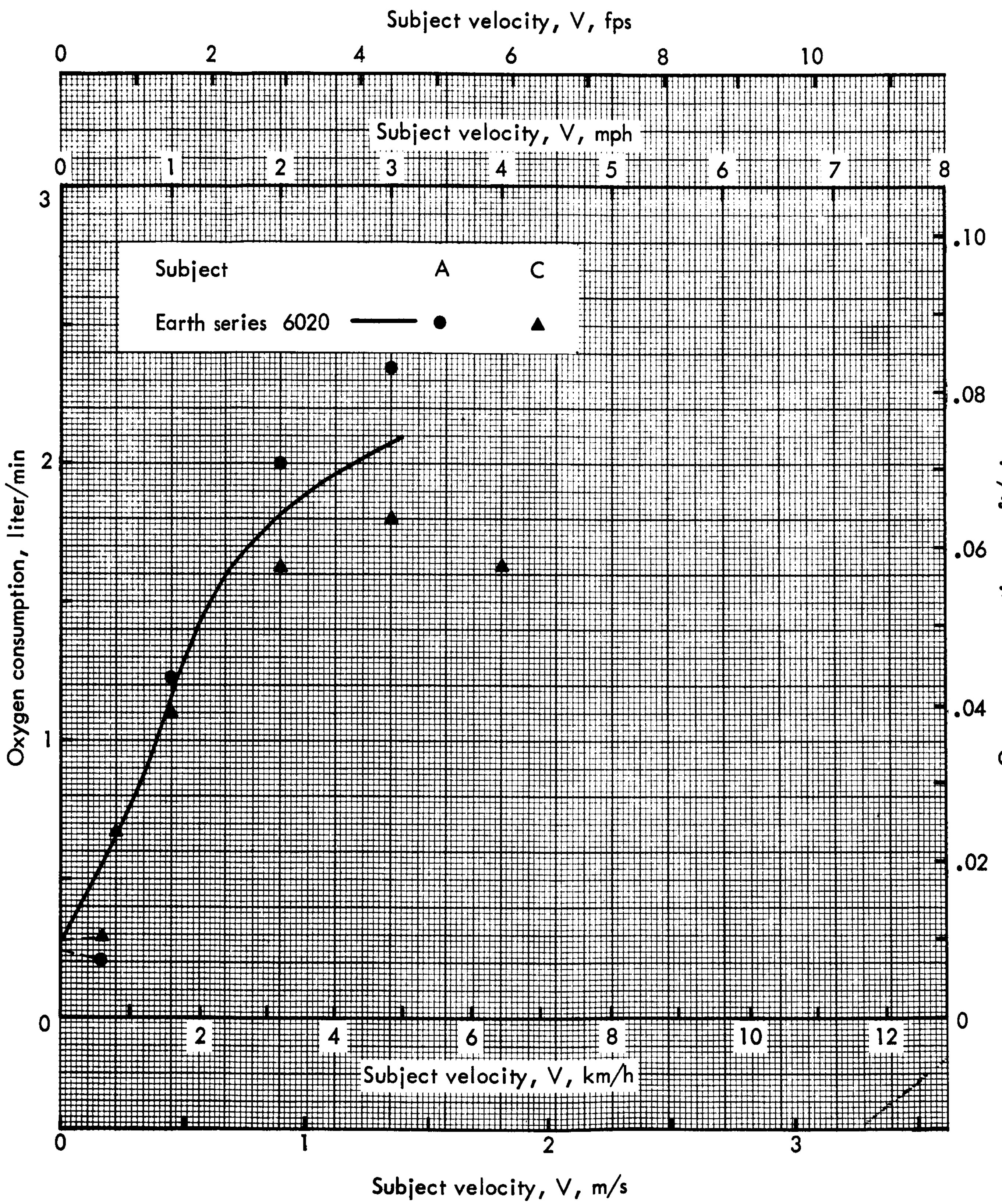


Figure 115. – Average oxygen consumption versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

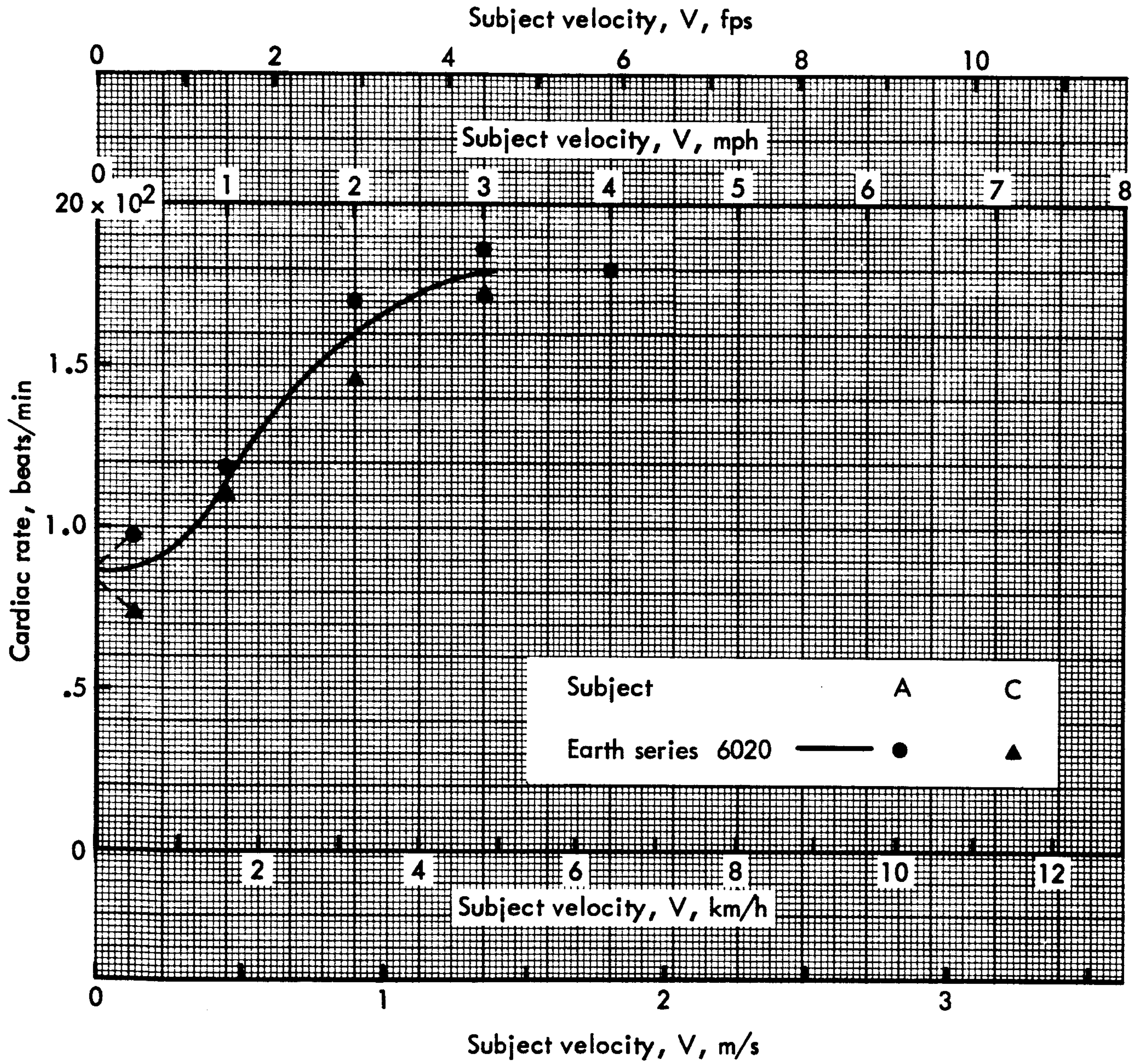


Figure 116. – Average cardiac rate versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

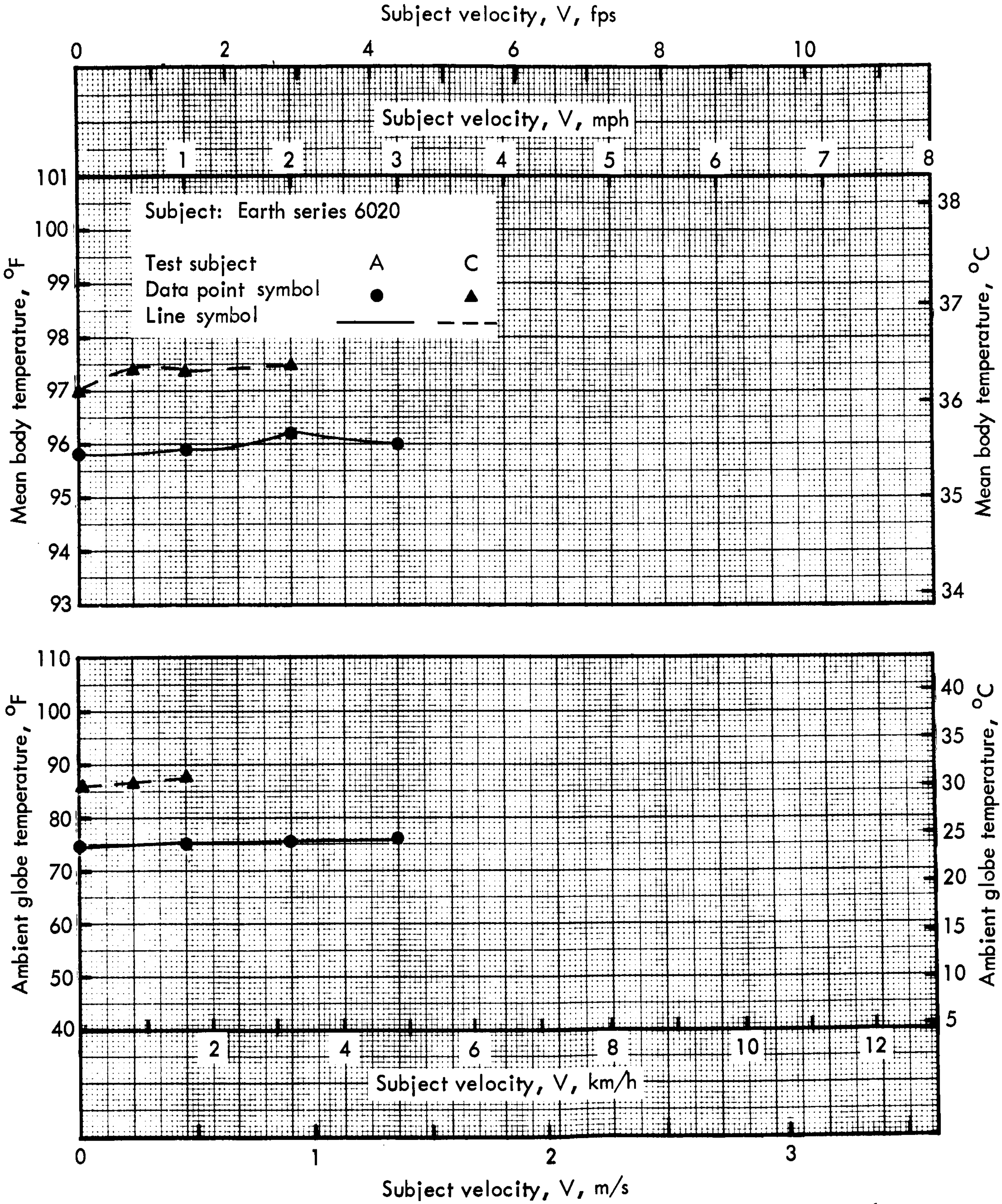


Figure 117. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 10 degrees walking.

Test Conditions: 1 g, shirtsleeve, susp. gear, pack I

Test Series 1030

Test Conditions:

Shirtsleeve x	Pressure suit in vent flow
	Pressure suit at 3.5 psig
Instrument Pack I x	Instrument Pack II
Work Activity walking	Work Variable ascending at 20°
Gravity: Lunar x	Earth

Test Location:

1/6 g Treadmill x	One g Treadmill

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	7	6	6

Respiration,	respiratory rate	Figure 118
	respiratory volume expired	Figure 119
Metabolism,	metabolic energy expenditure rate	Figure 120
	metabolic energy expenditure rate per unit length	Figure 121
	oxygen consumption	Figure 122
	oxygen consumption per unit length	Figure 123
Cardiovascular function,	cardiac rate	Figure 124
Body temperature,	mean body temperature	Figure 125
Pressure suit environmental data		Not Obtained

Comments:

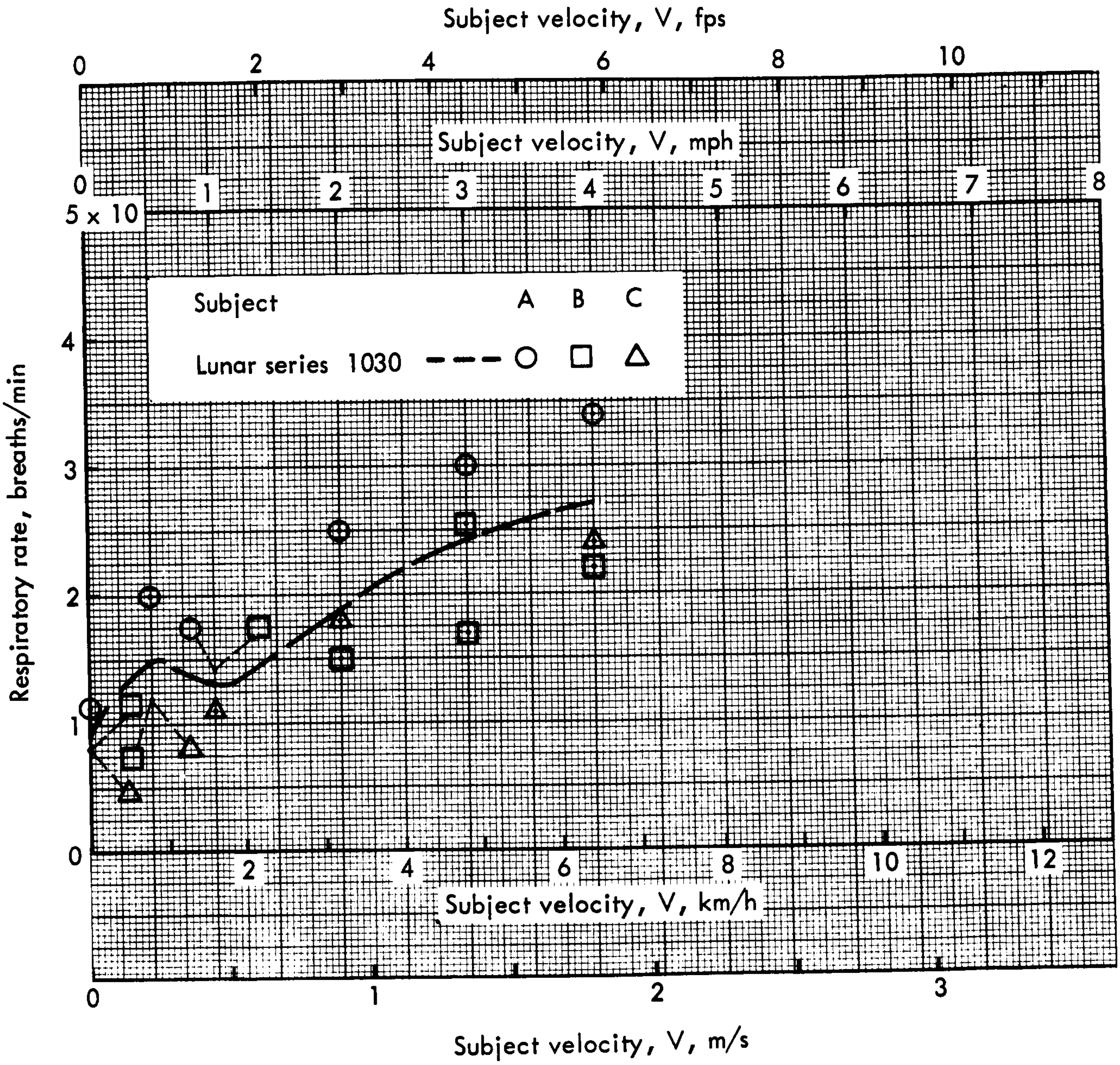


Figure 118. – Average respiratory rate versus subject velocity ascending at 20 degrees walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

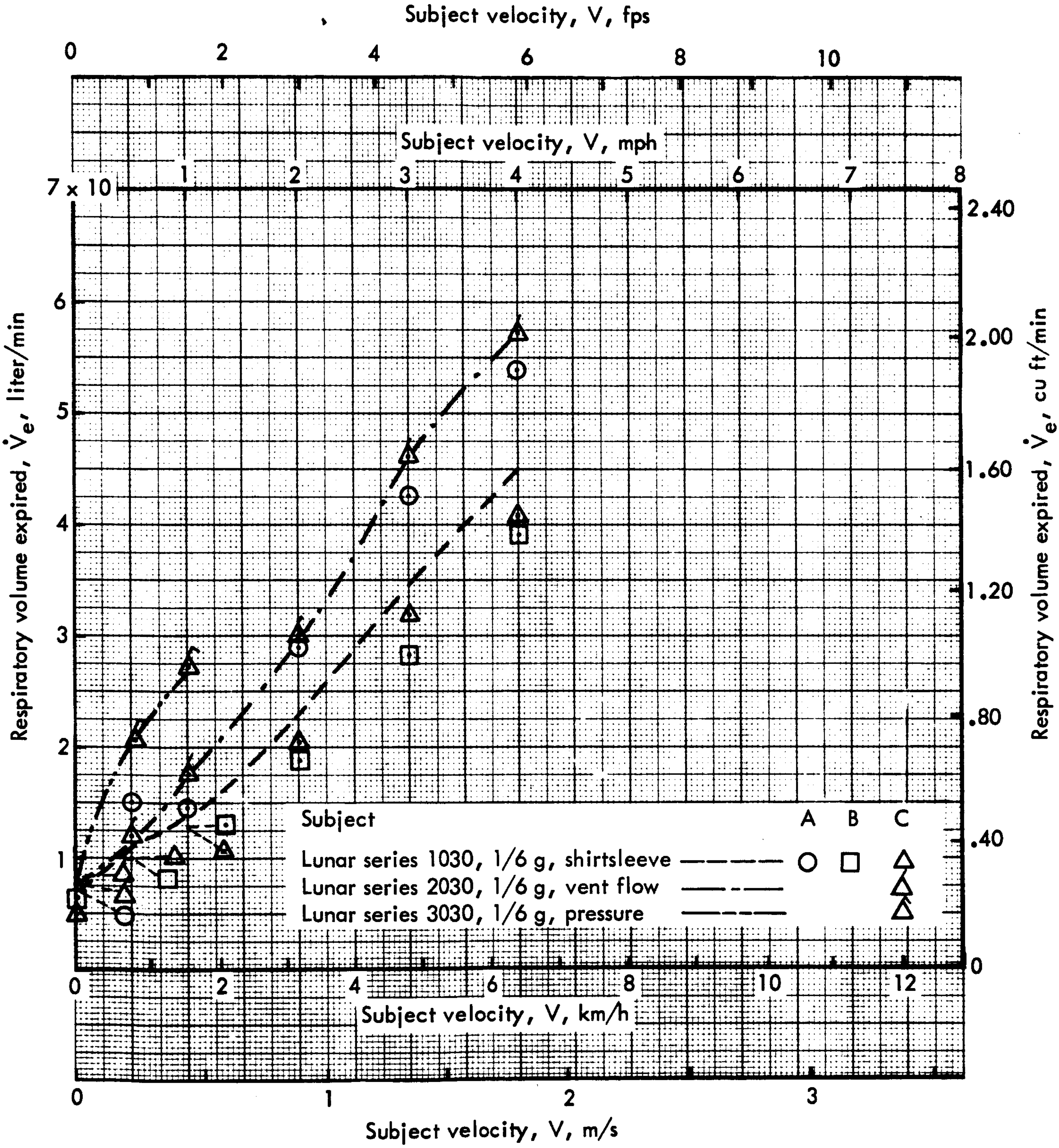


Figure 119. – Average mean respiratory volume versus subject velocity ascending at 20 degrees walking.

Comparison of 1/6 g test conditions between shirtsleeve, vent flow and pressure

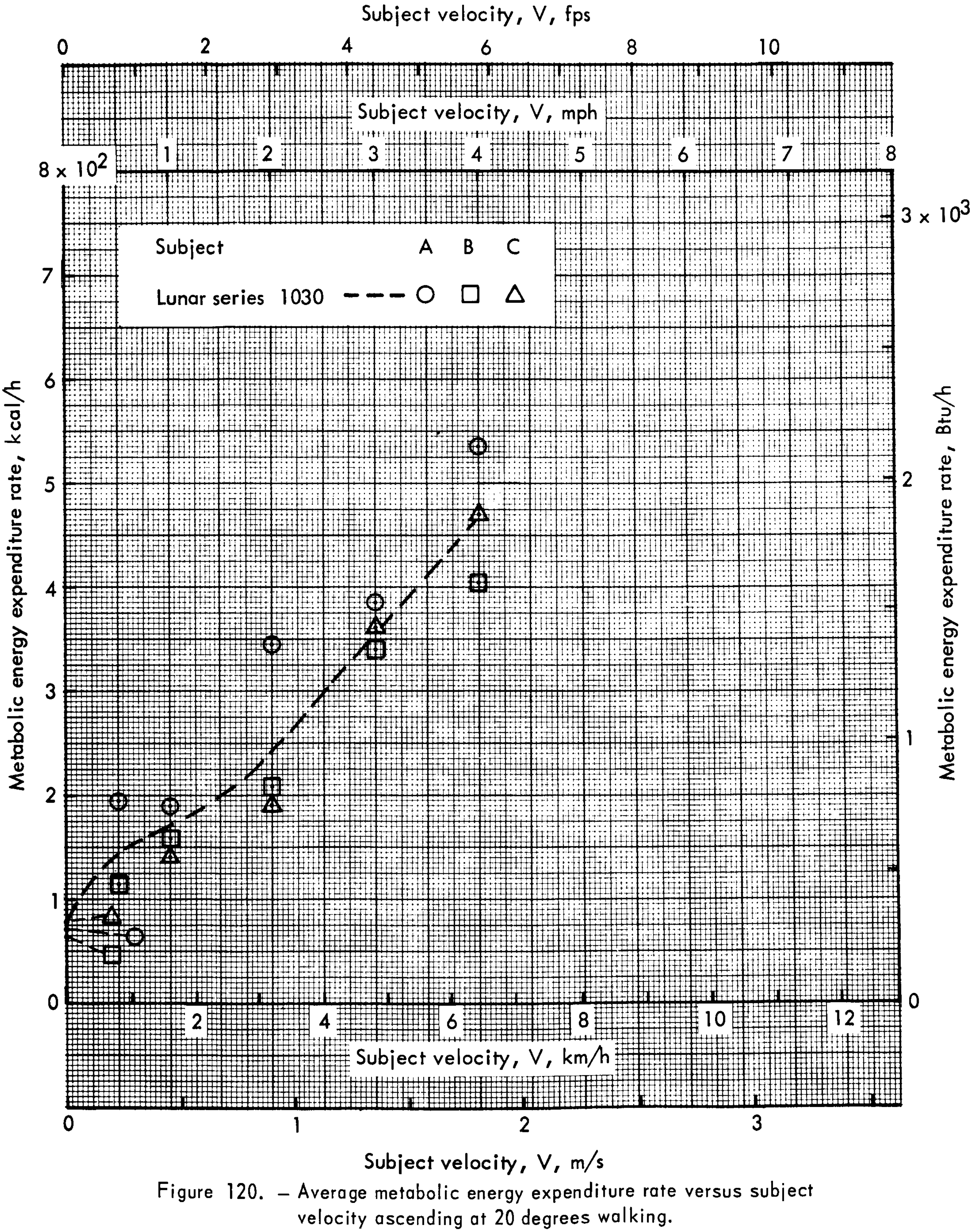


Figure 120. – Average metabolic energy expenditure rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

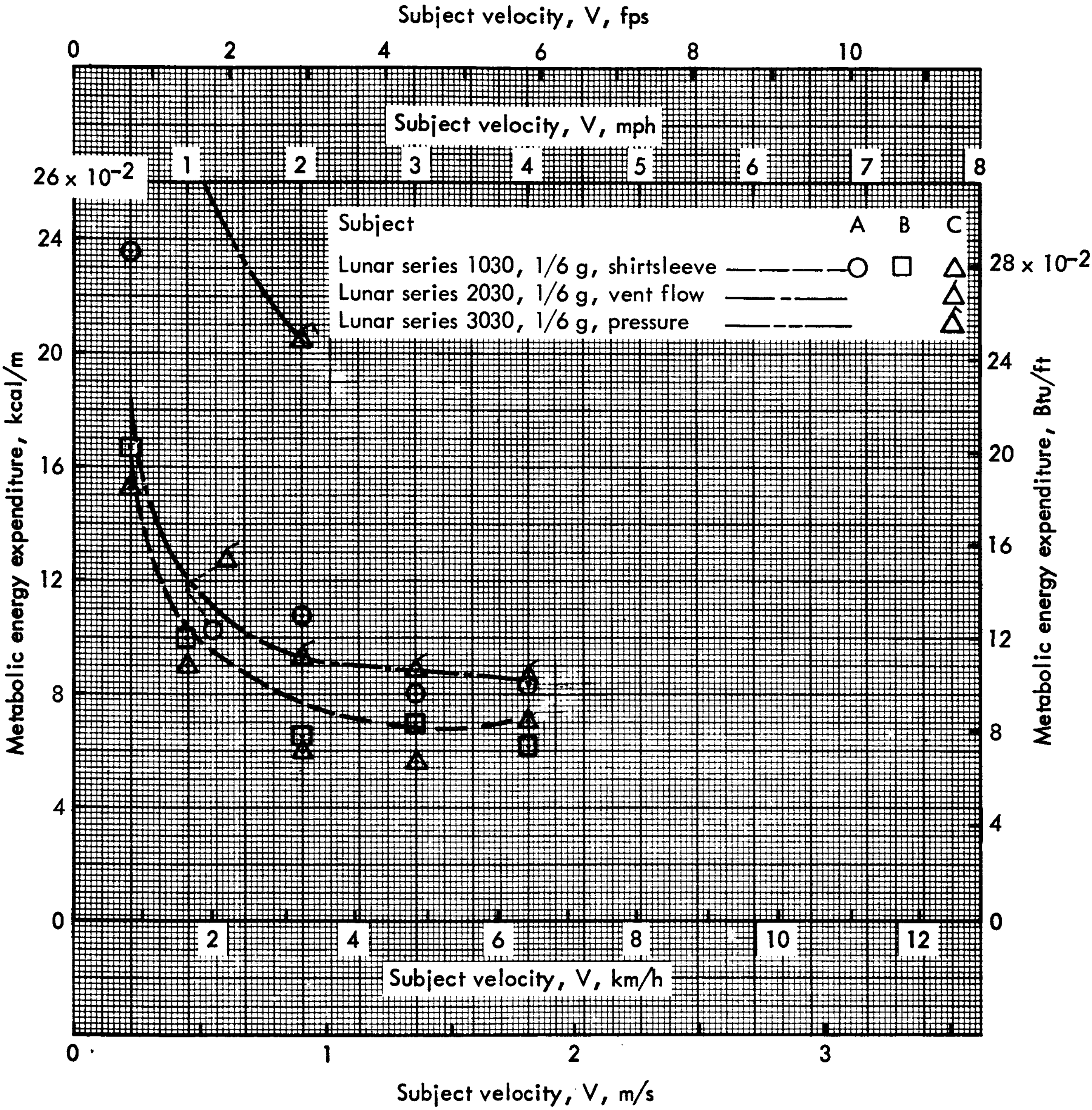
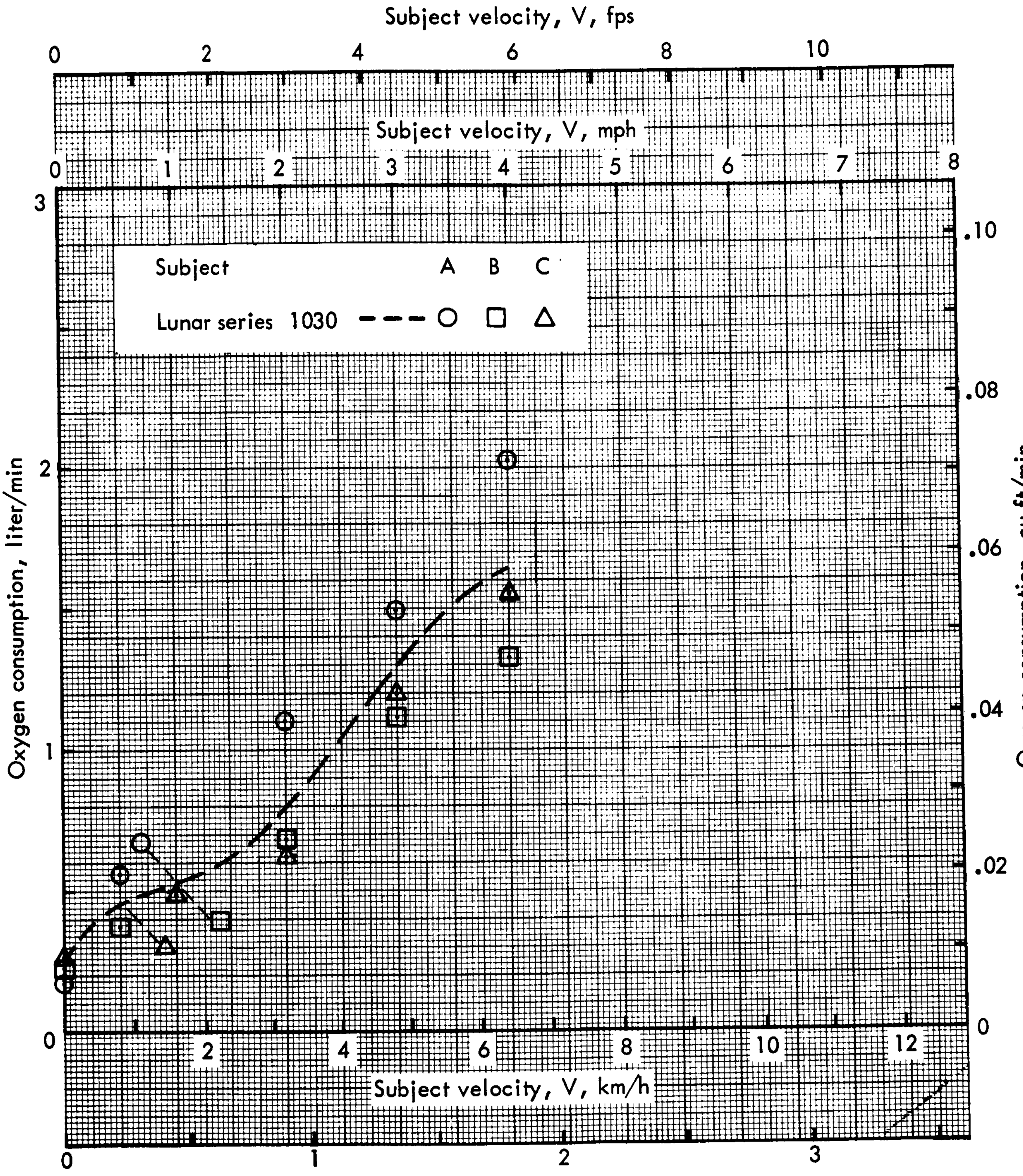


Figure 121. – Average metabolic energy expenditure per unit length versus subject velocity in ascending at 20 degrees walking.

Comparison of 1/6 g test conditions between shirtsleeve, vent flow and pressure



Subject velocity, V, m/s

Figure 122. – Average oxygen consumption versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

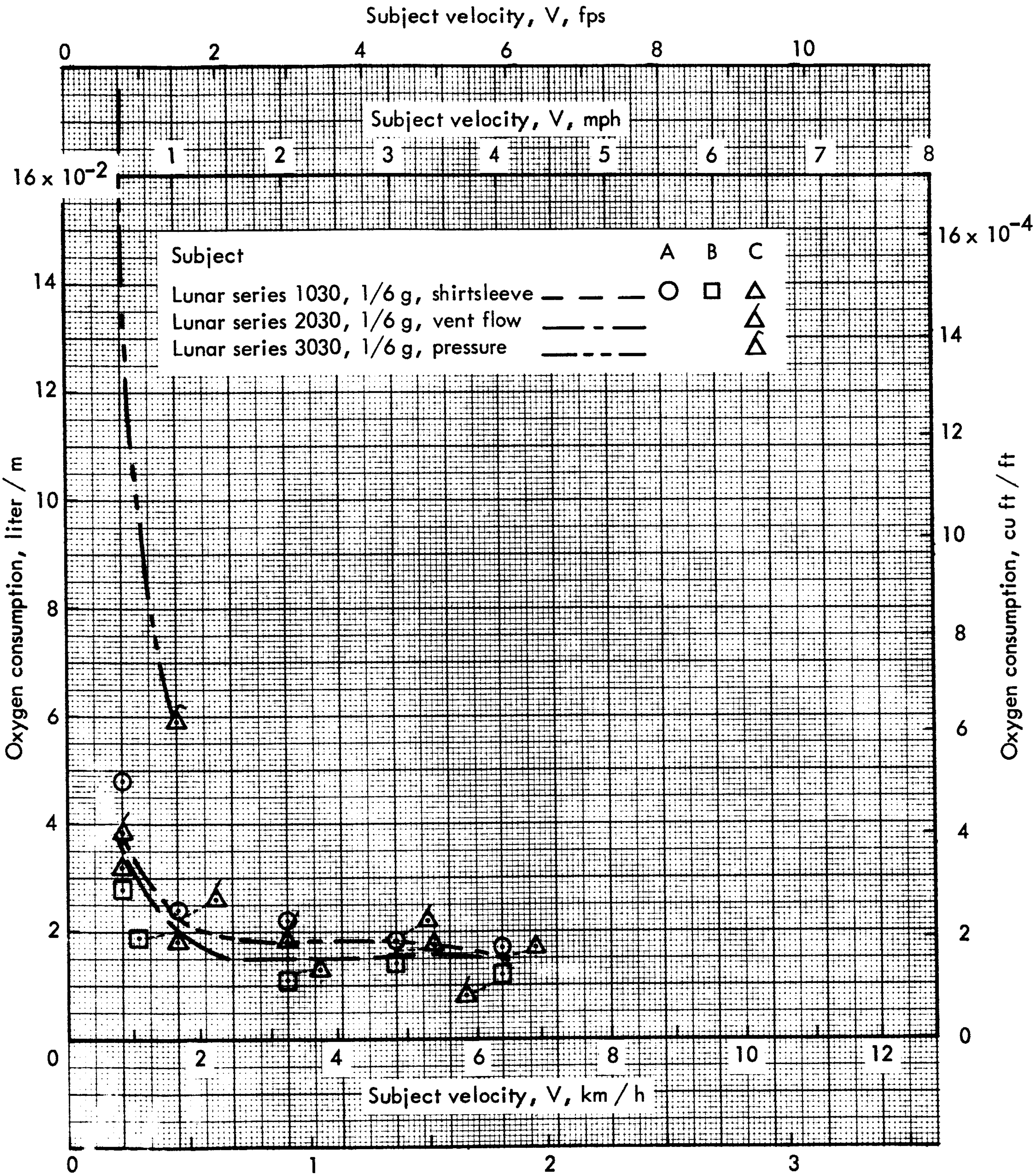


Figure 123. – Average oxygen consumption per unit length versus subject velocity ascending at 20 degrees walking.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

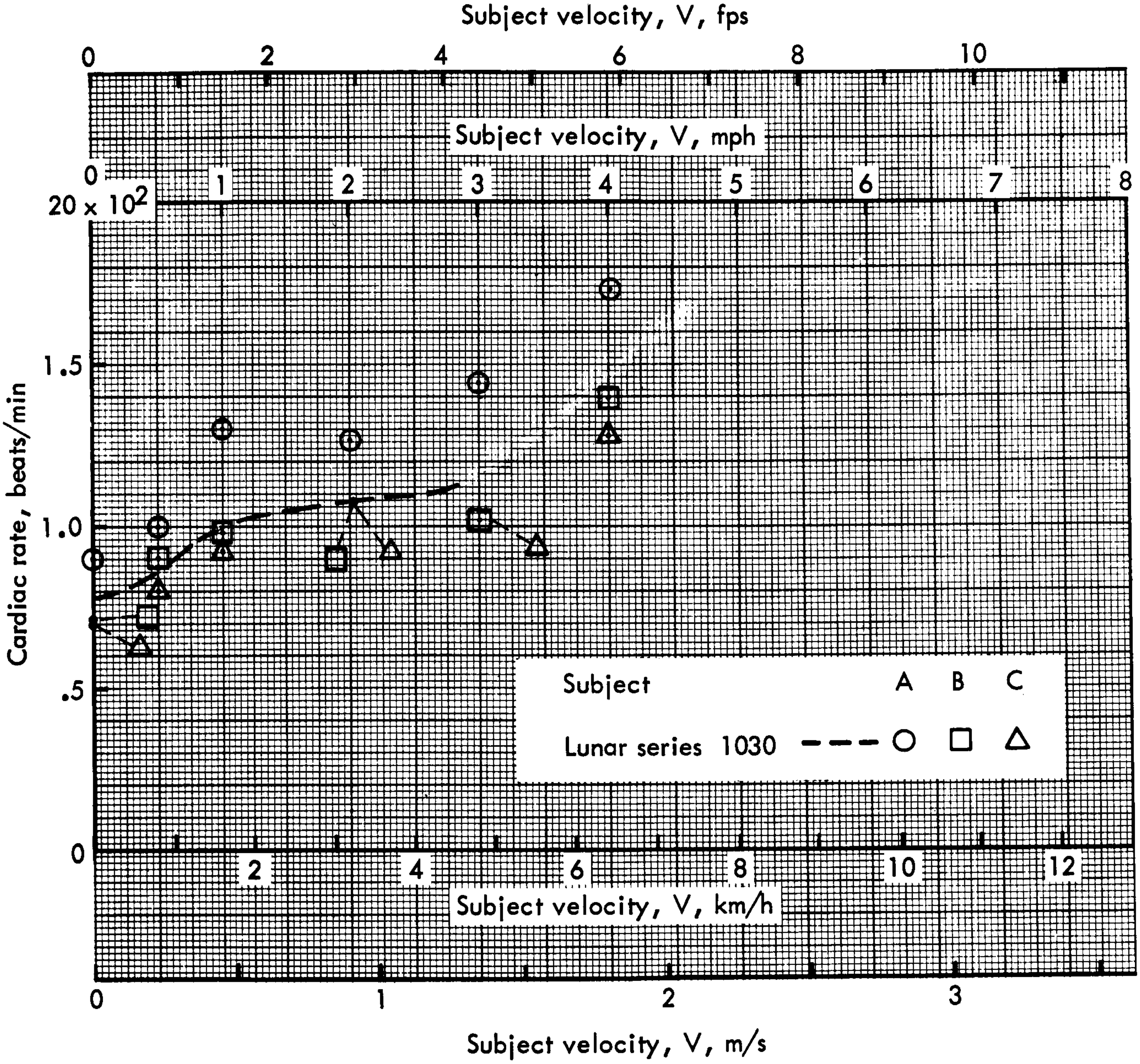


Figure 124. – Average cardiac rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

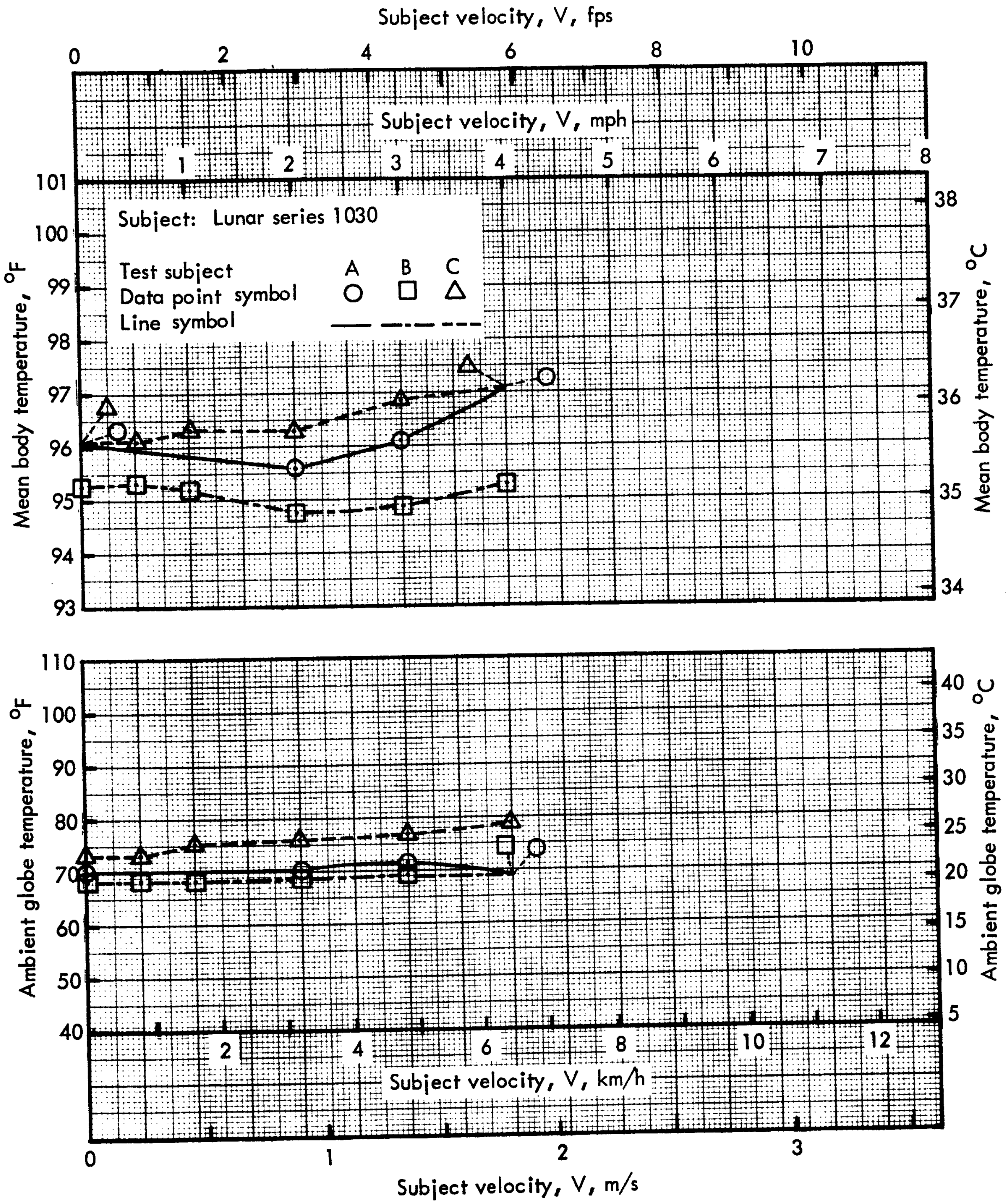


Figure 125. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2030

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	ascending at 20°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

Results for Subject	A	B	C
			x
Number of Tests			6

Respiration, respiratory rate	Figure 126*
respiratory volume expired	
Metabolism, metabolic energy expenditure rate	Figure 127
metabolic energy expenditure rate per unit length	Figure 121
oxygen consumption	Figure 128
oxygen consumption per unit length	Figure 123
Cardiovascular function, cardiac rate	Figure 129
Body temperature, mean body temperature	Figure 130
Pressure suit environmental data	Figure 131

Comments:

*Figure 126 was modified according to intermediate averages

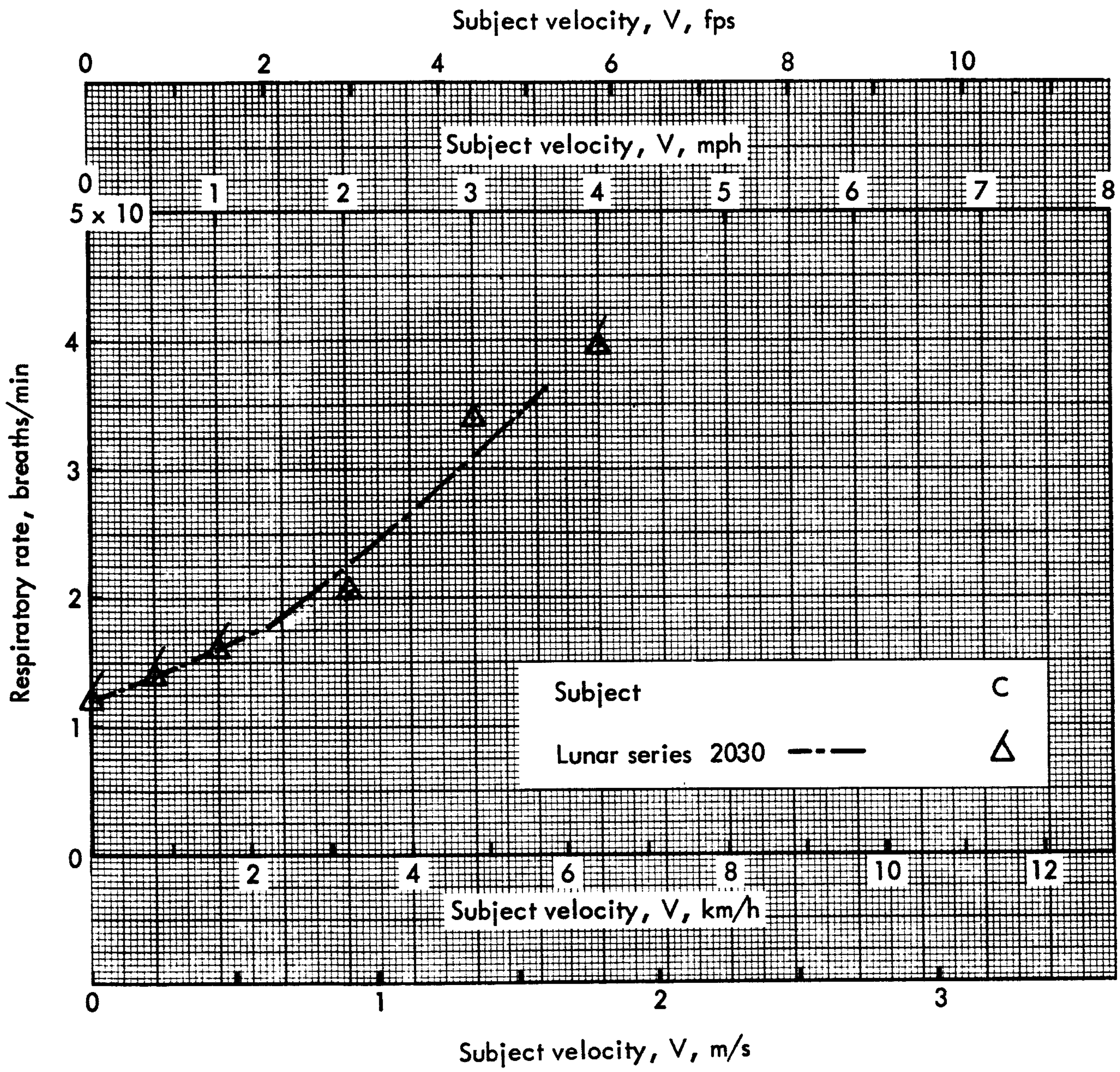


Figure 126. – Respiratory rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

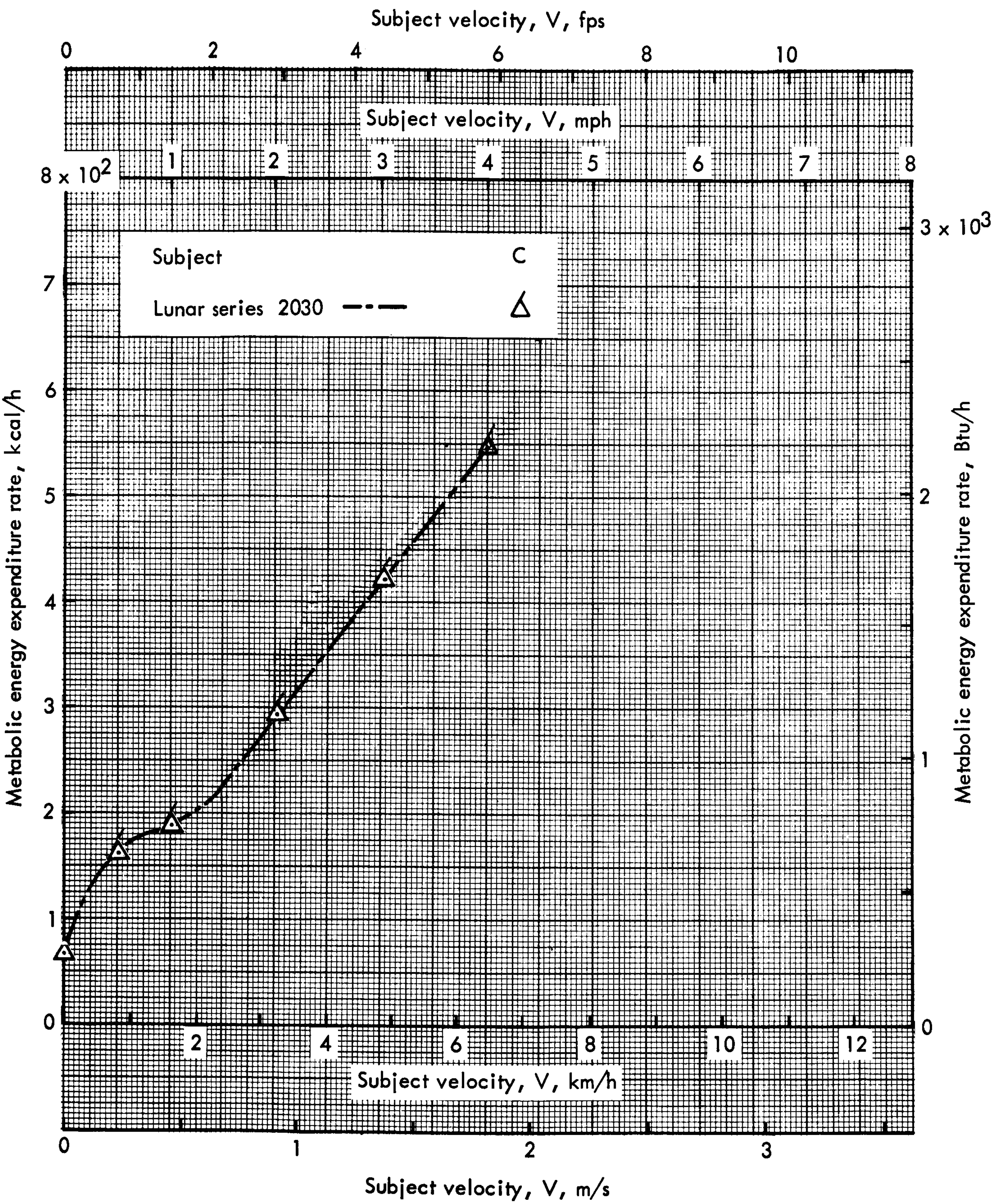


Figure 127. – Metabolic energy expenditure rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

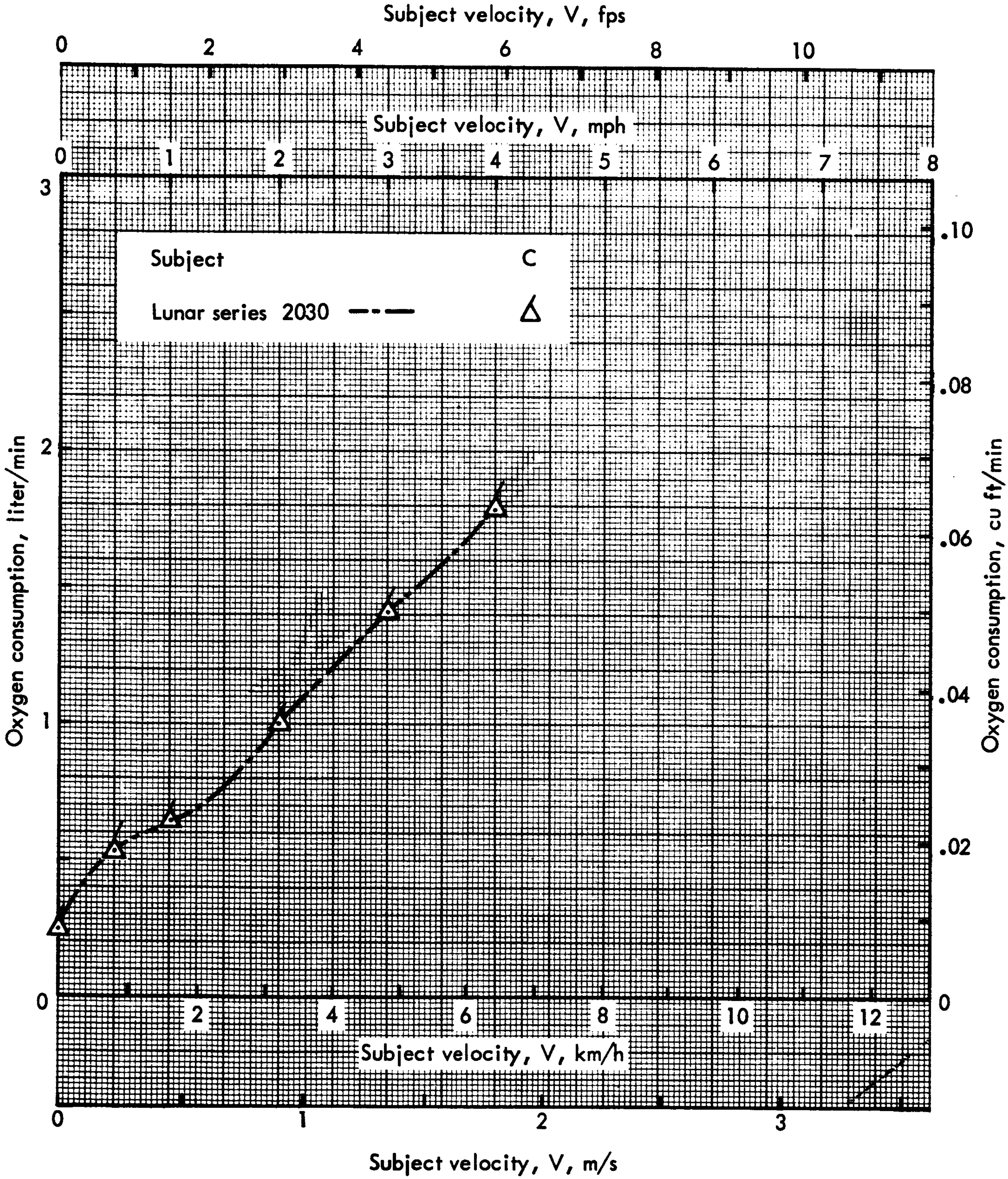


Figure 128. – Oxygen consumption versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1 g, pressure suit-pressurized, susp. gear, pack II

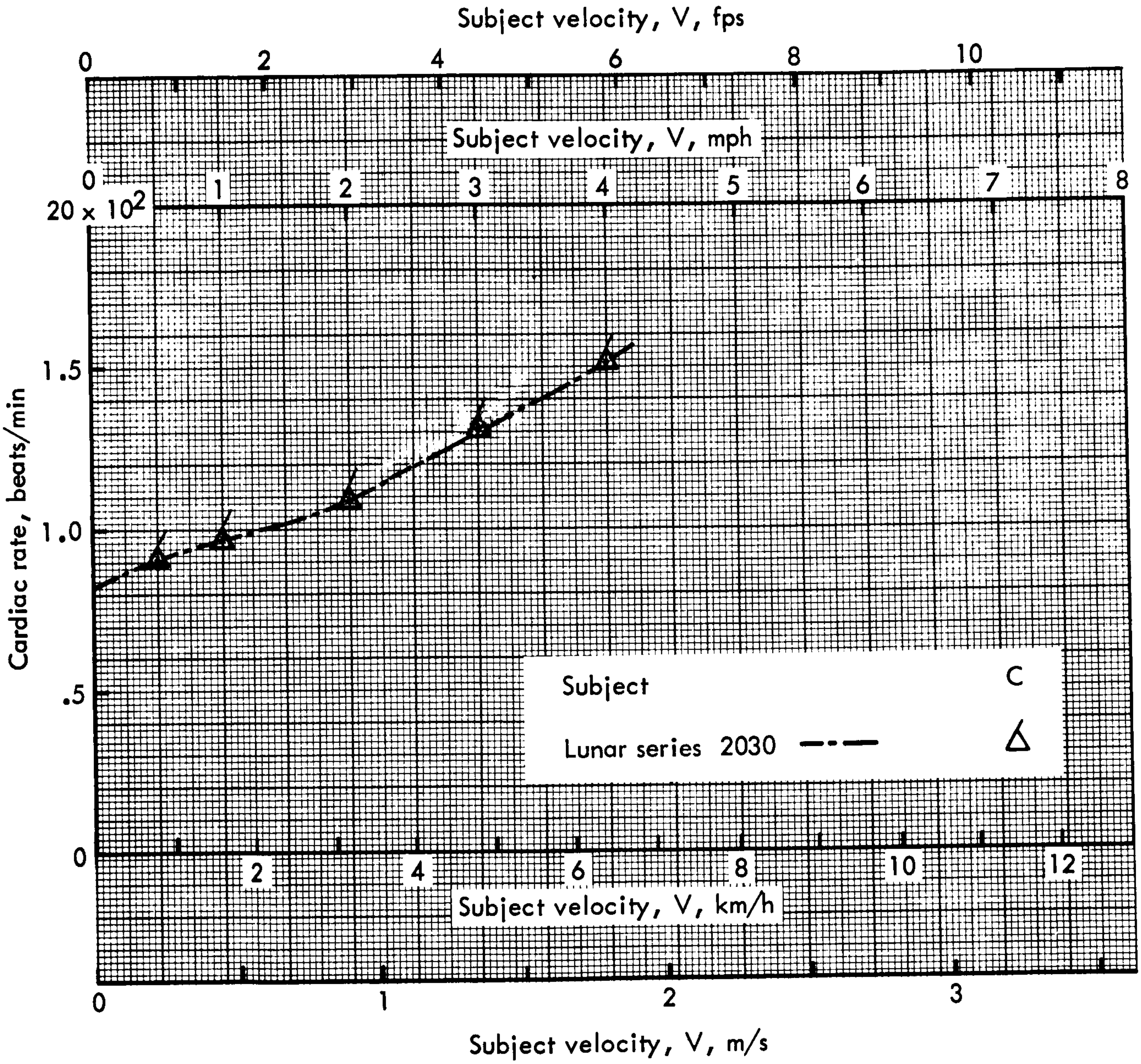


Figure 129. – Cardiac rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

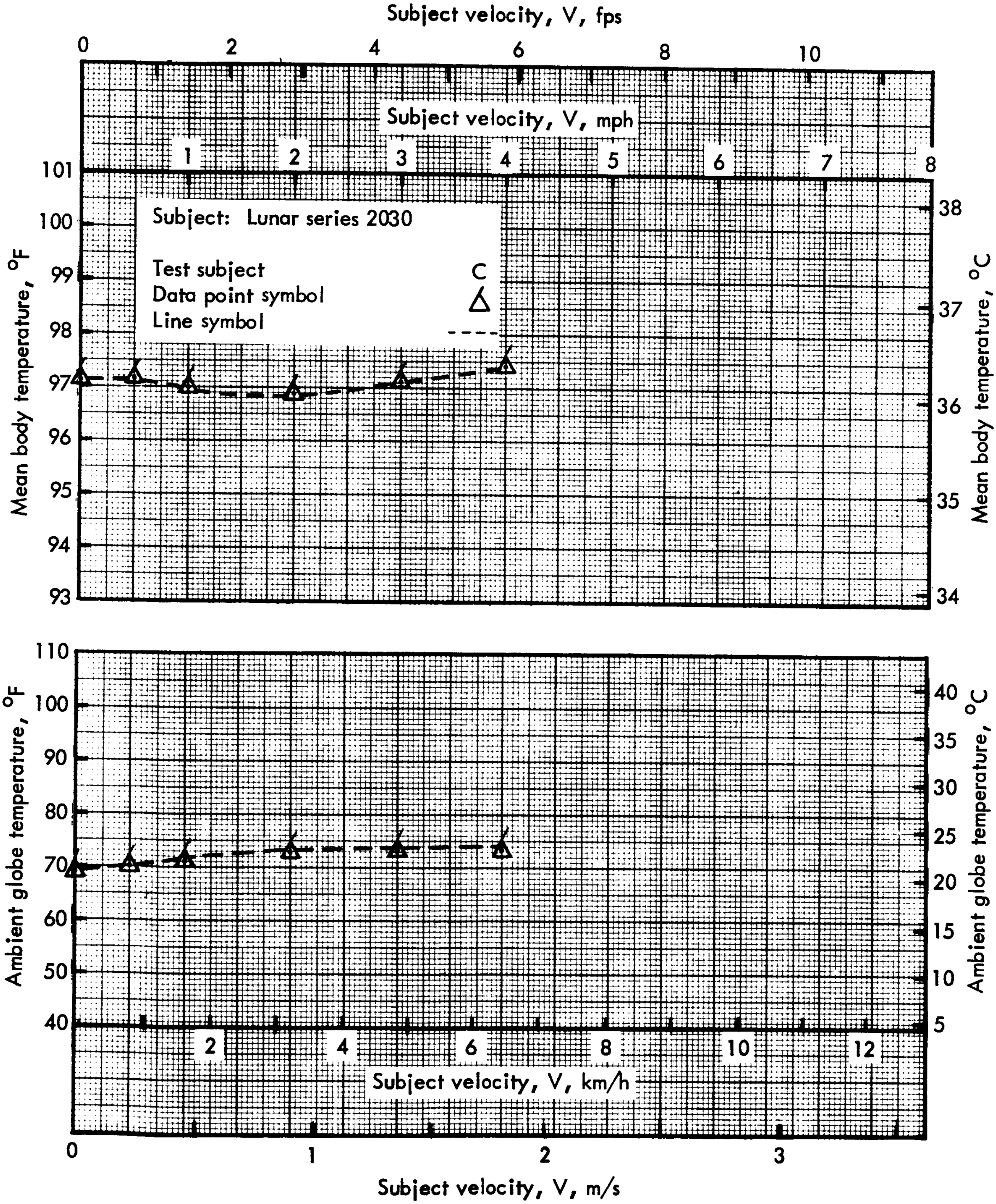


Figure 130. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 20 degrees walking.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

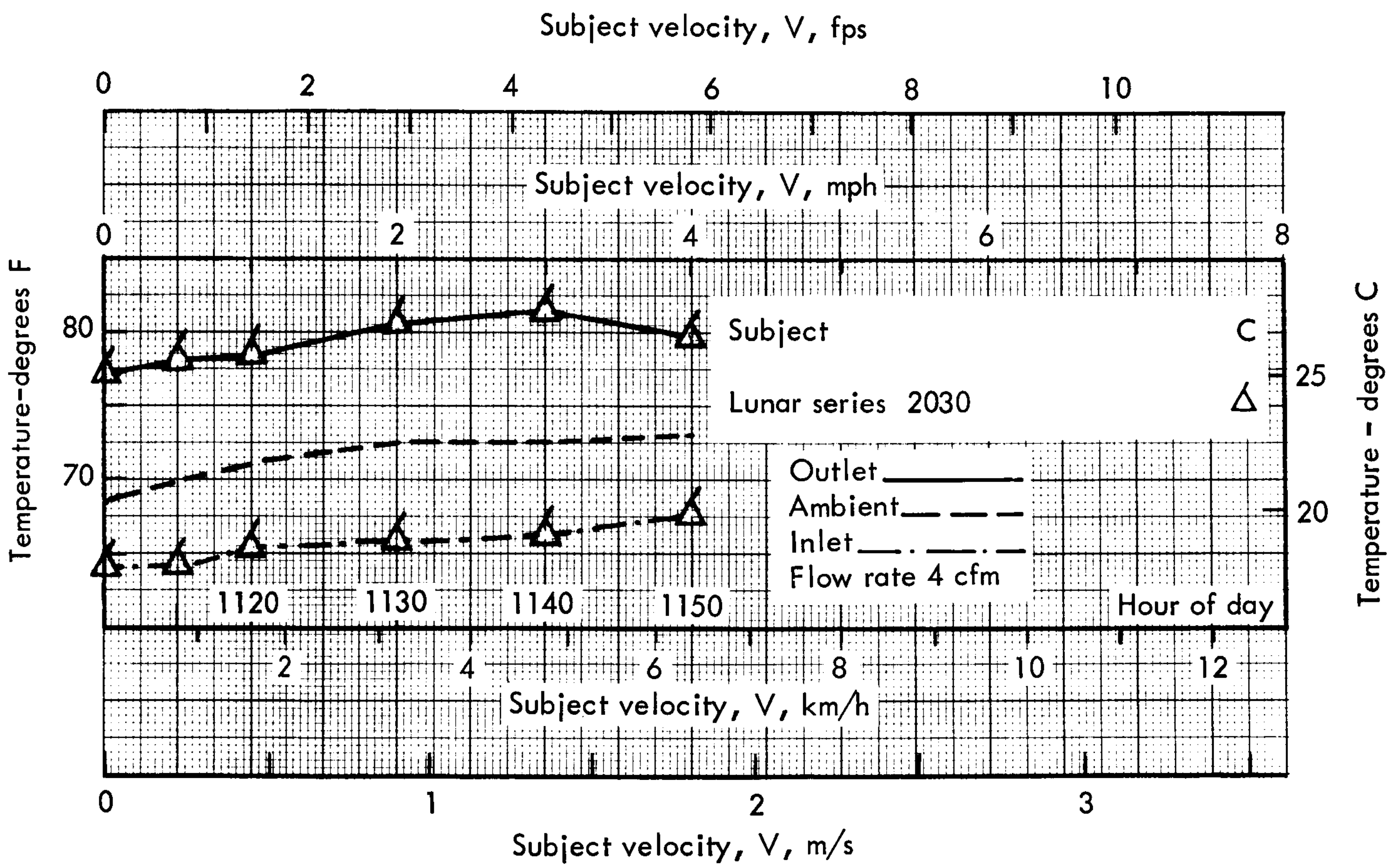


Figure 131. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3030

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	ascending at 20°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			3

Respiration, respiratory rate	Figure 132
respiratory volume expired	Figure 119
Metabolism, metabolic energy expenditure rate	Figure 133
metabolic energy expenditure rate per unit length	Figure 121
oxygen consumption	Figure 134
oxygen consumption per unit length	Figure 123
Cardiovascular function, cardiac rate	Figure 135
Body temperature, mean body temperature	Figure 136
Pressure suit environmental data	Figure 137

Comments:

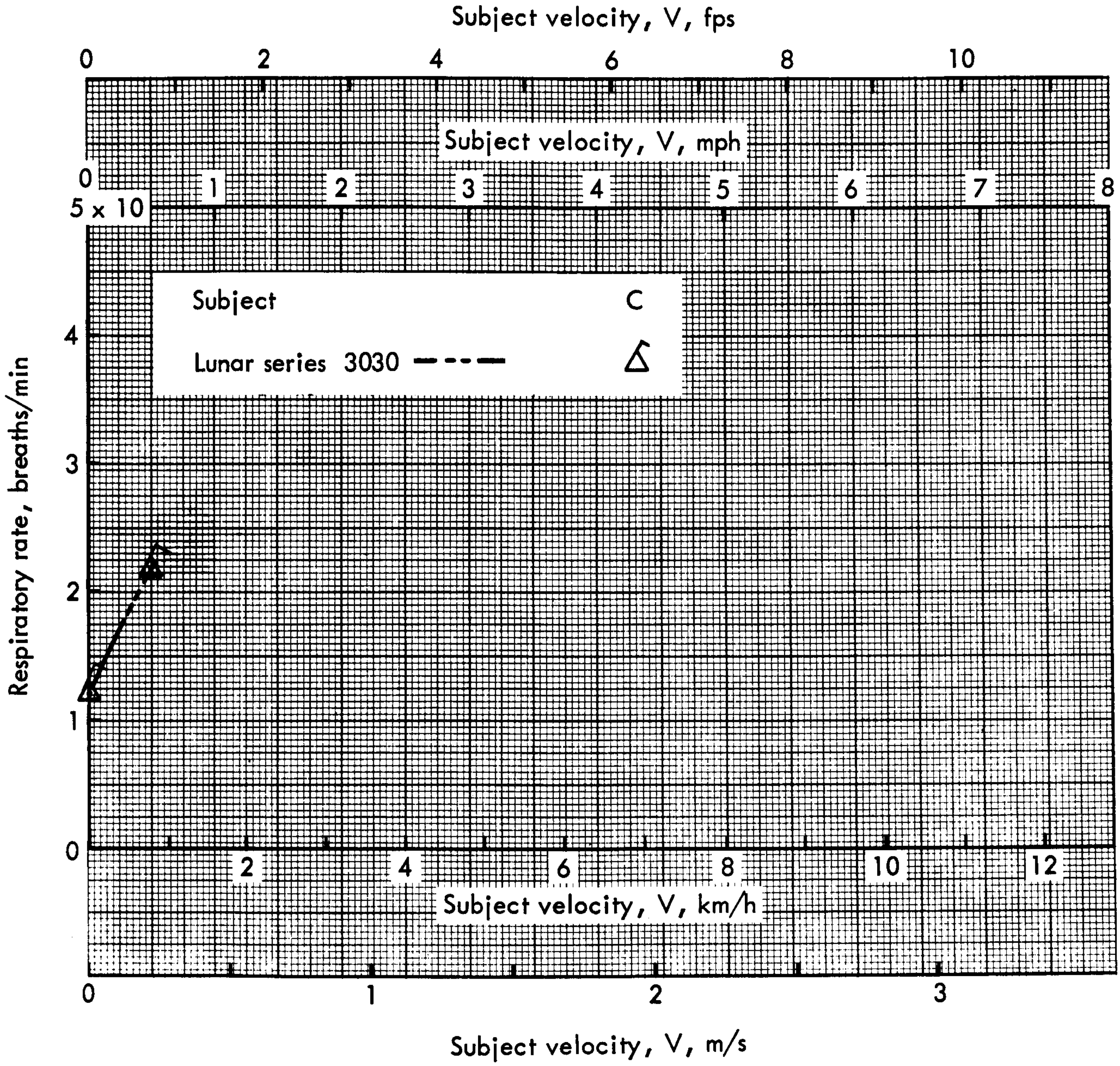


Figure 132. – Respiratory rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

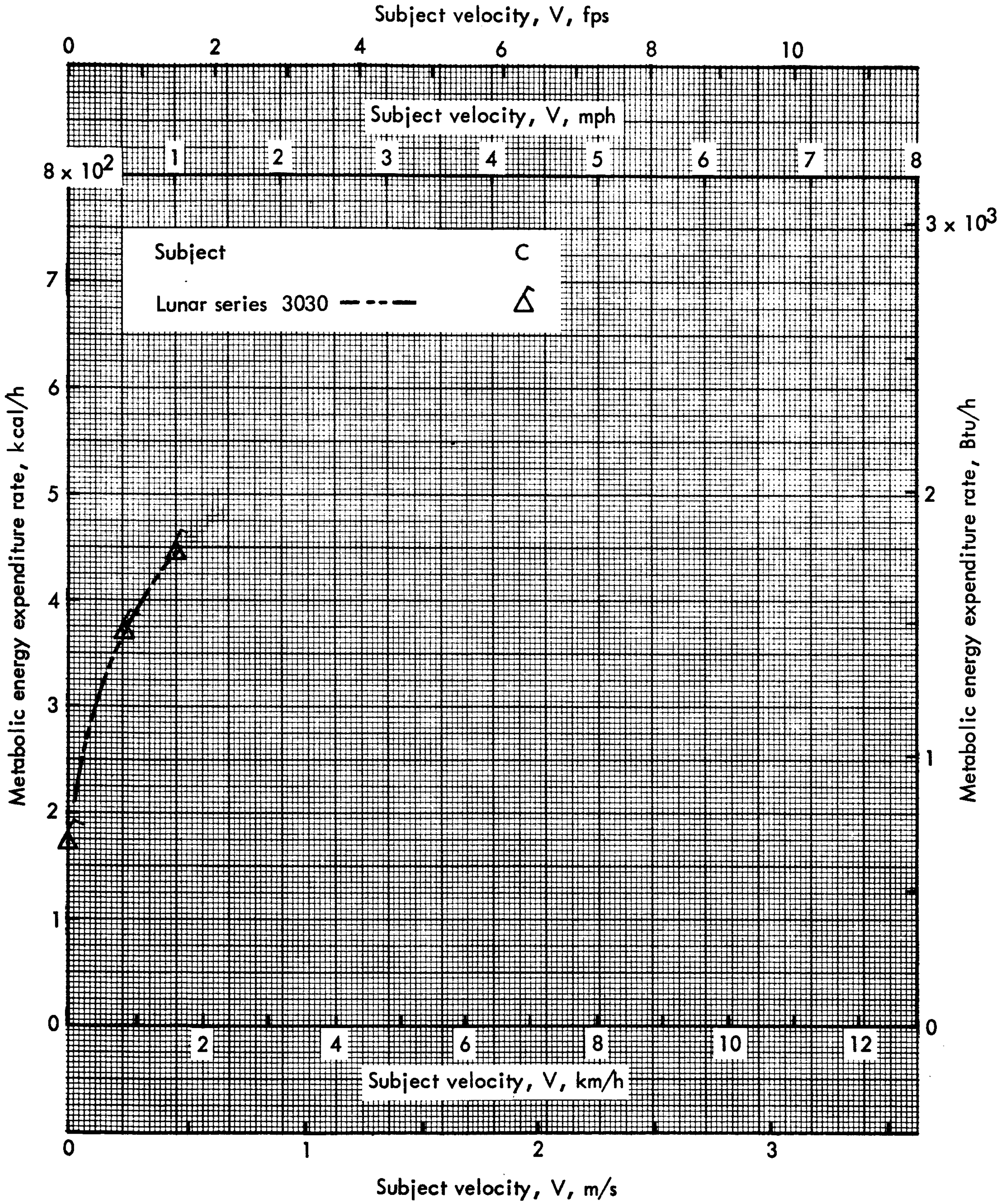


Figure 133. – Metabolic energy expenditure rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

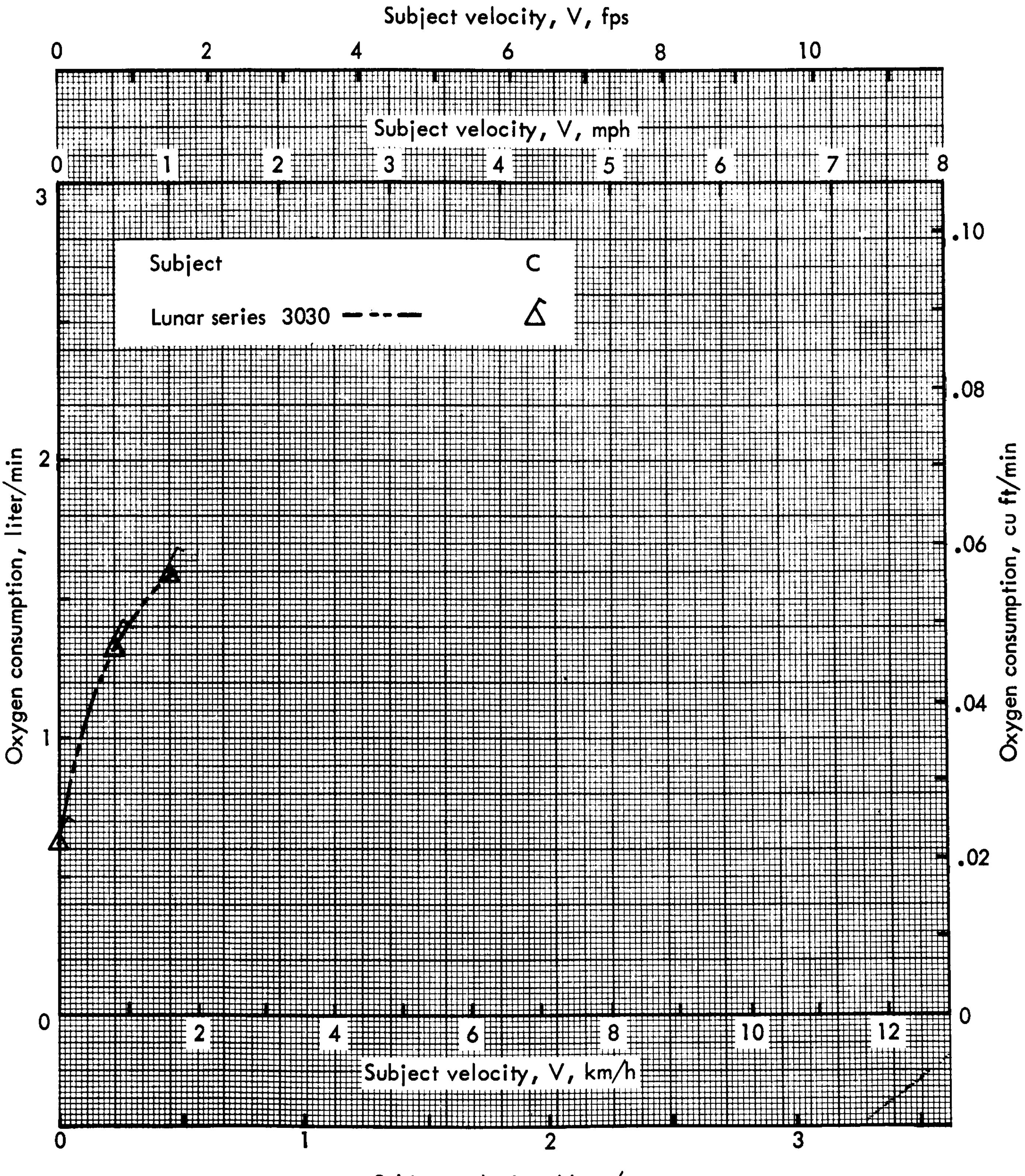


Figure 134. – Oxygen consumption versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

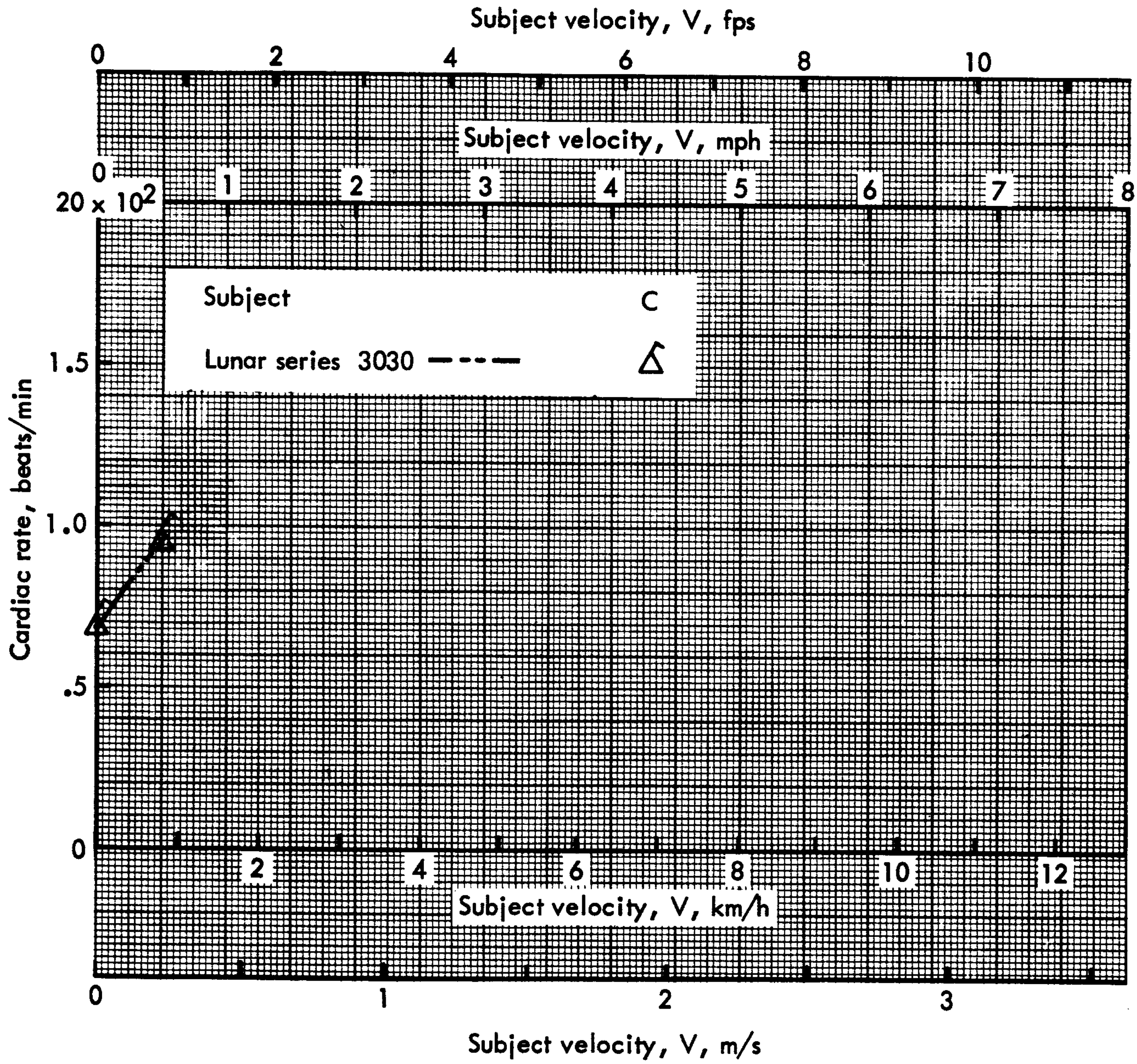


Figure 135. – Cardiac rate versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

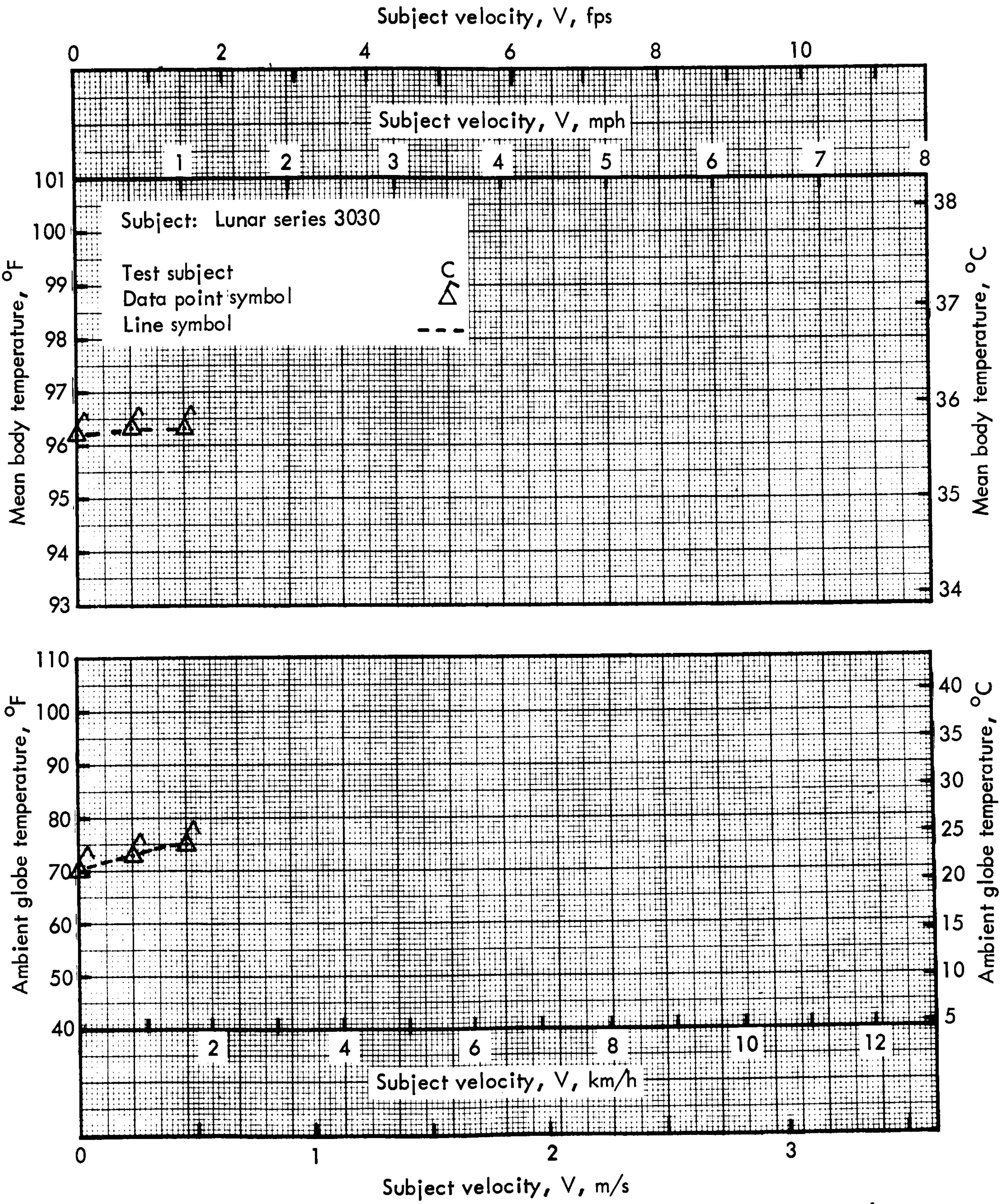


Figure 136. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

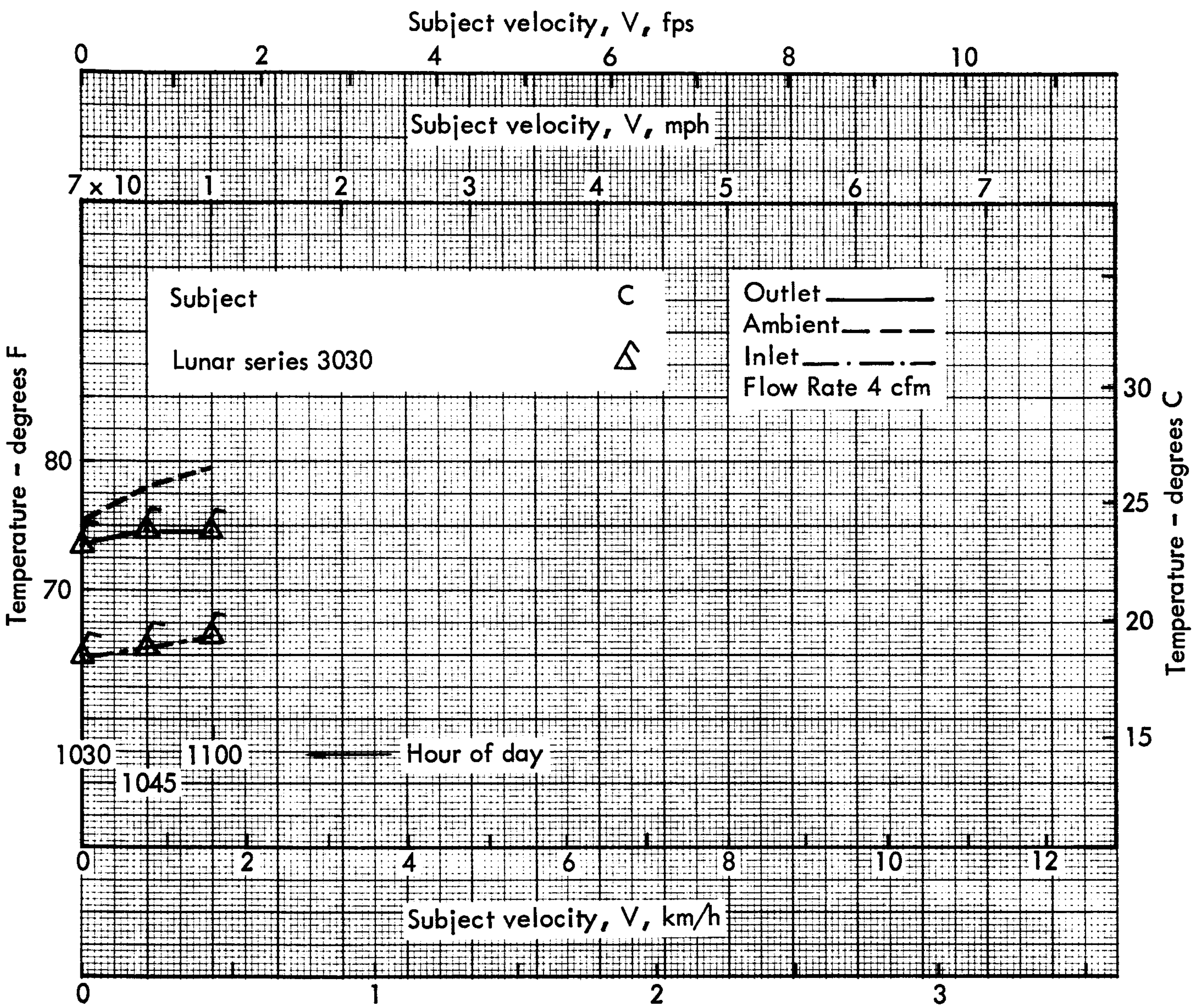


Figure 137. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, ascending at 20 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series 1040

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking	Work Variable	ascending at 30°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	5		5

Respiration, respiratory rate	Figure 138
respiratory volume expired	Figure 139
Metabolism, metabolic energy expenditure rate	Figure 140
metabolic energy expenditure rate per unit length	Figure 141
oxygen consumption	Figure 142
oxygen consumption per unit length	Figure 143
Cardiovascular function, cardiac rate	Figure 144
Body temperature, mean body temperature	Figure 145
Pressure suit environmental data	Not Obtained

Comments:

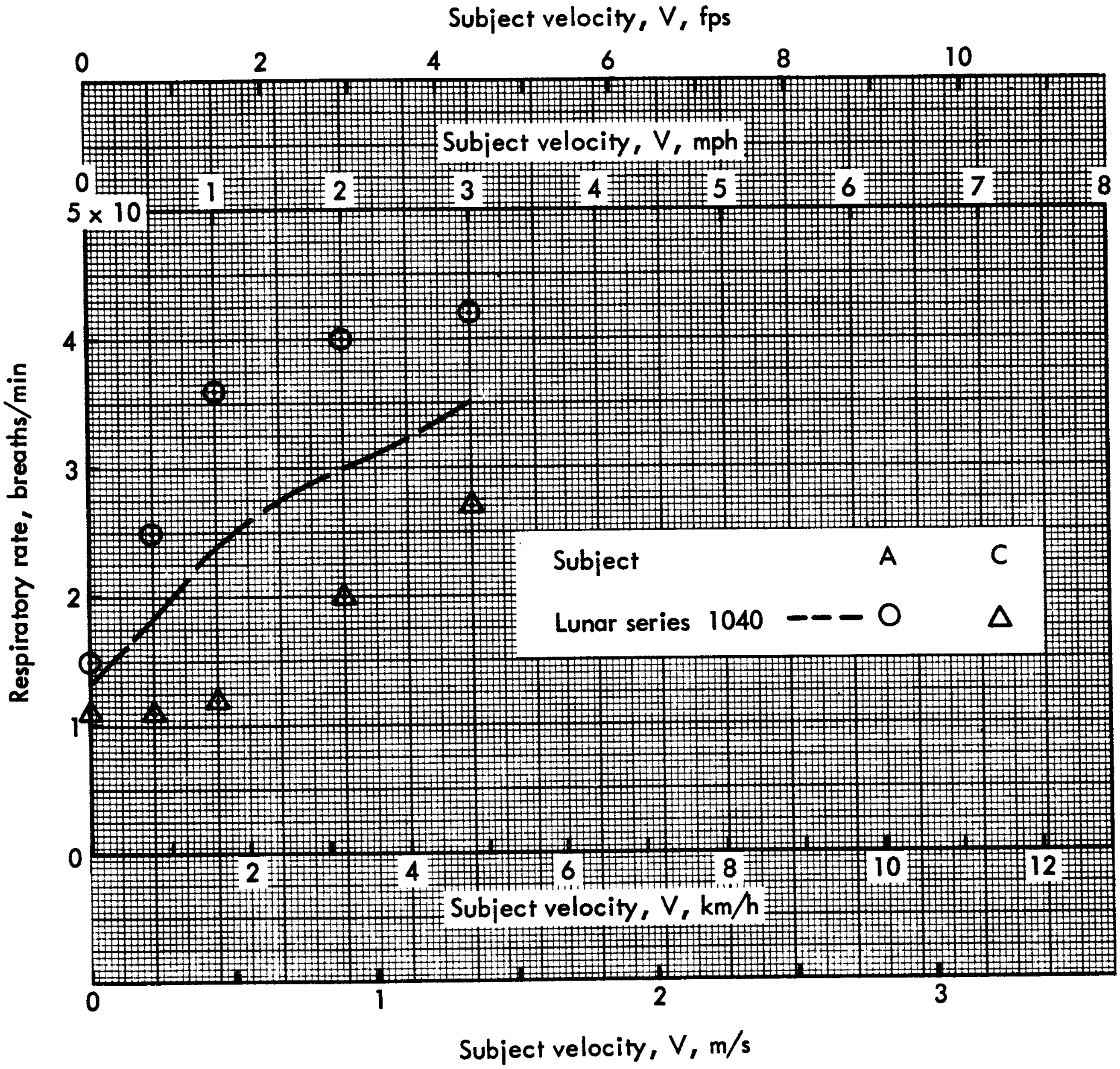


Figure 138. – Average respiratory rate versus subject velocity ascending at 30 degrees walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

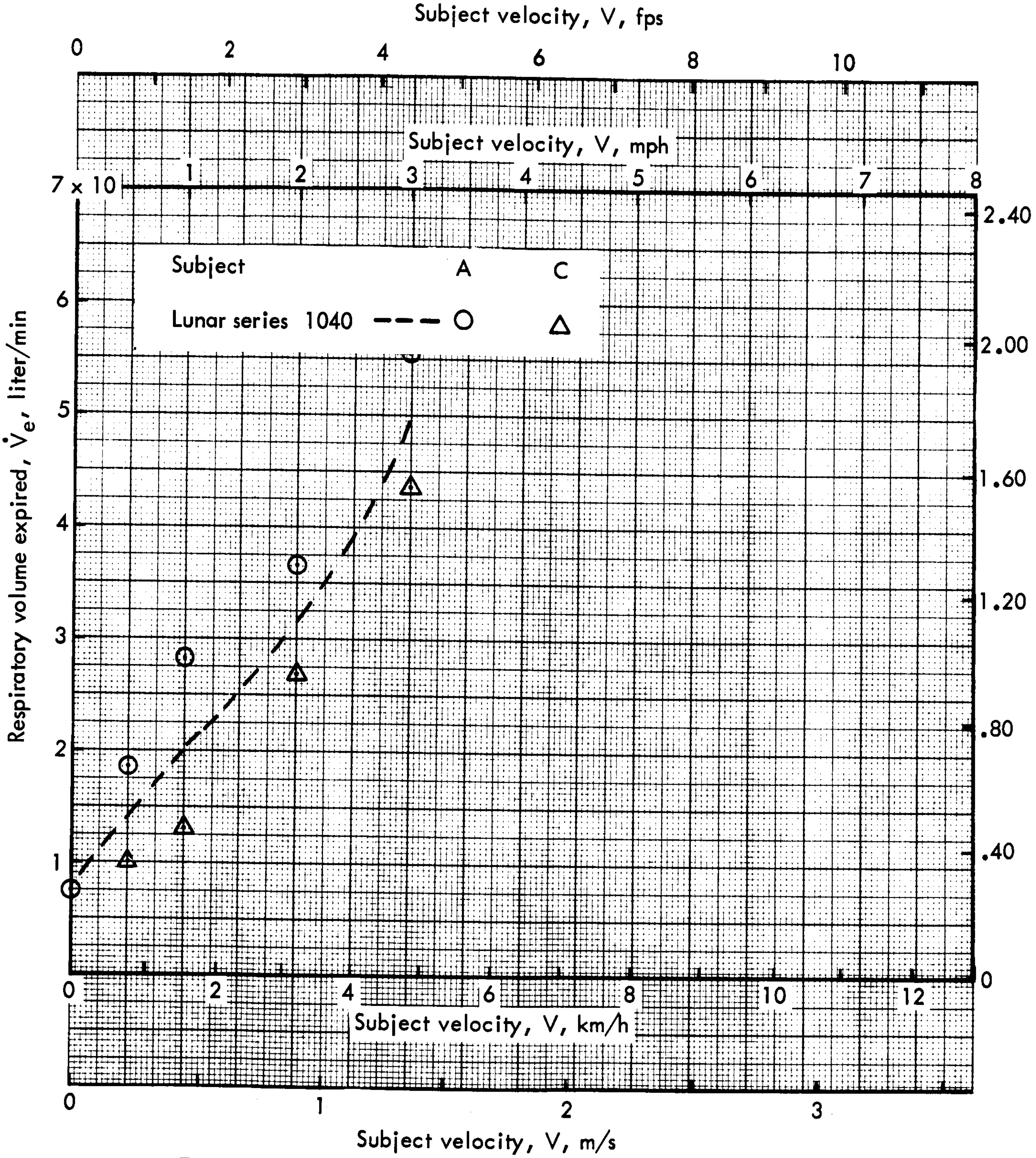


Figure 139. – Average mean respiratory volume versus subject velocity ascending at 30 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

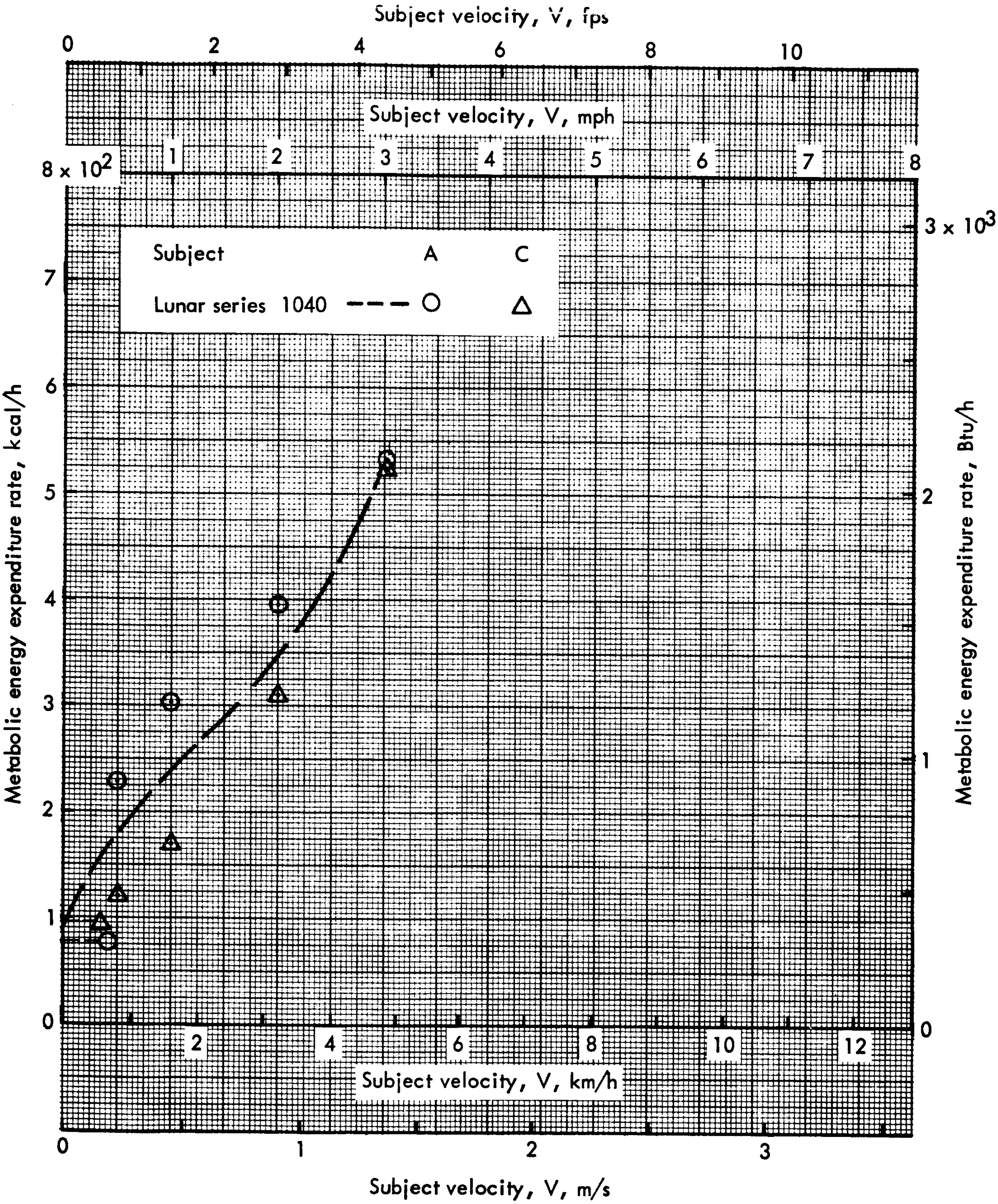


Figure 140. – Average metabolic energy expenditure rate versus subject velocity ascending at 30 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

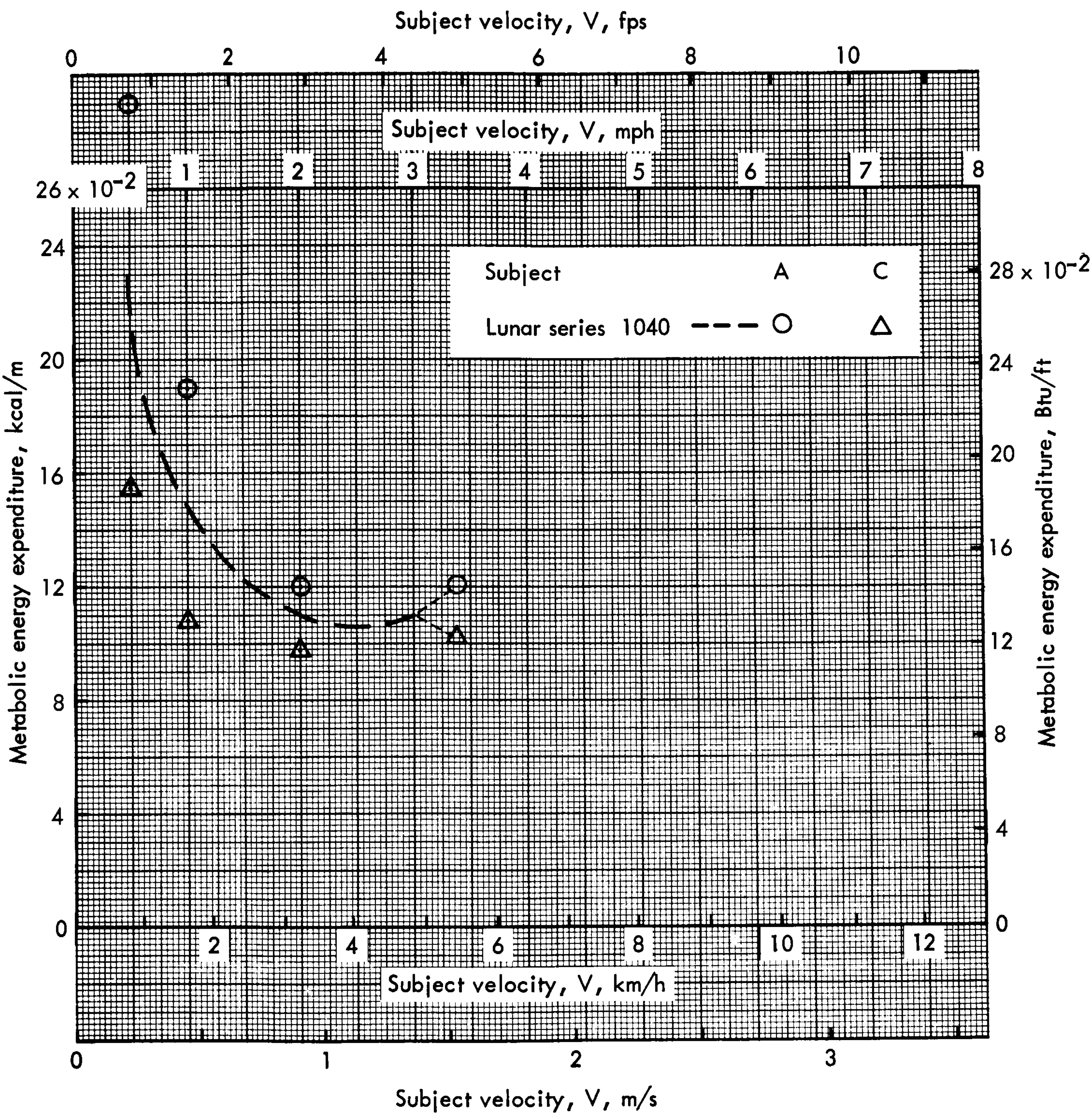


Figure 141. – Average metabolic energy expenditure per unit length versus subject velocity ascending at 30 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

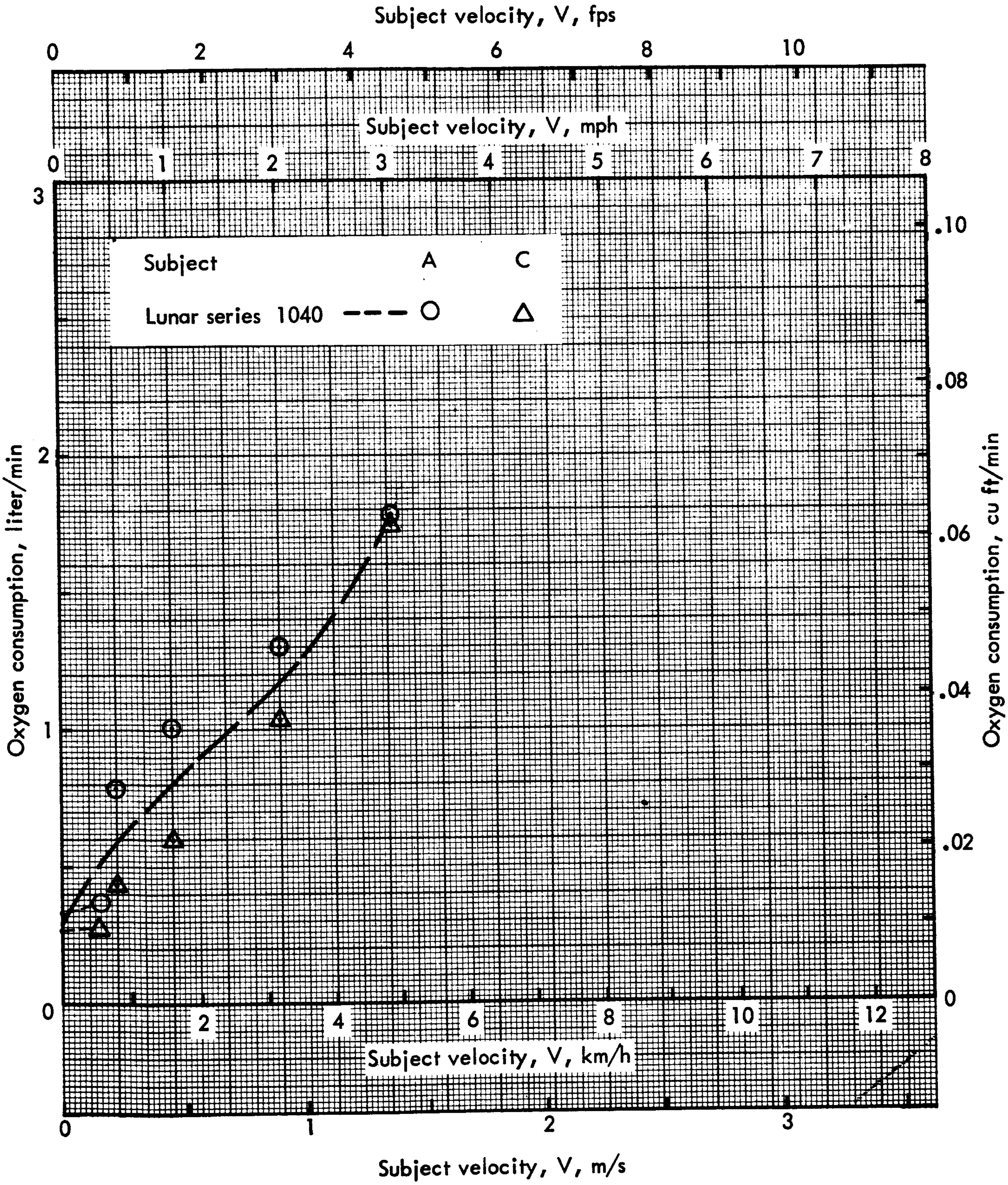


Figure 142. – Average oxygen consumption versus subject velocity ascending at 30 degrees walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

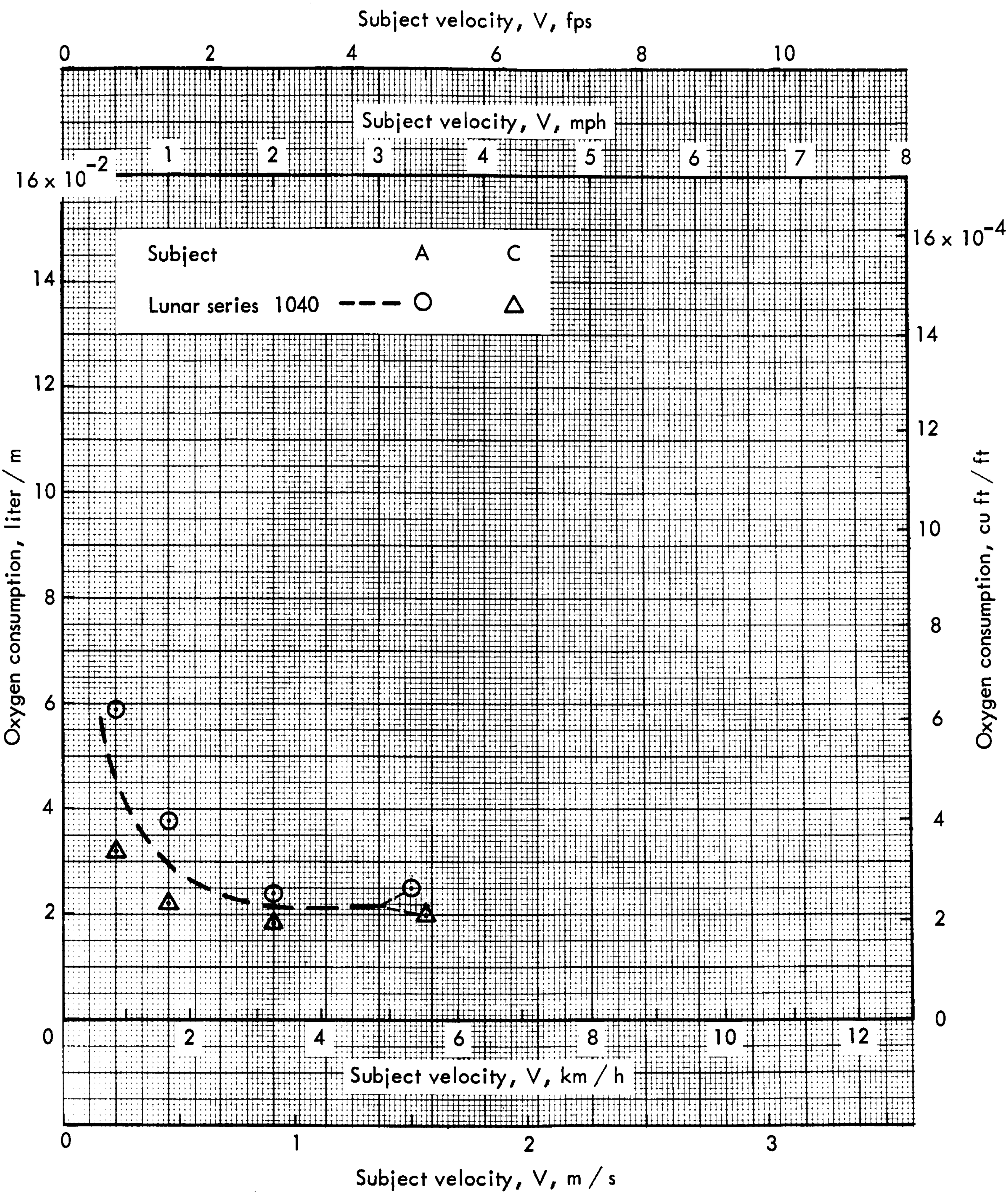


Figure 143. – Average oxygen consumption per unit length versus subject velocity ascending at 30 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

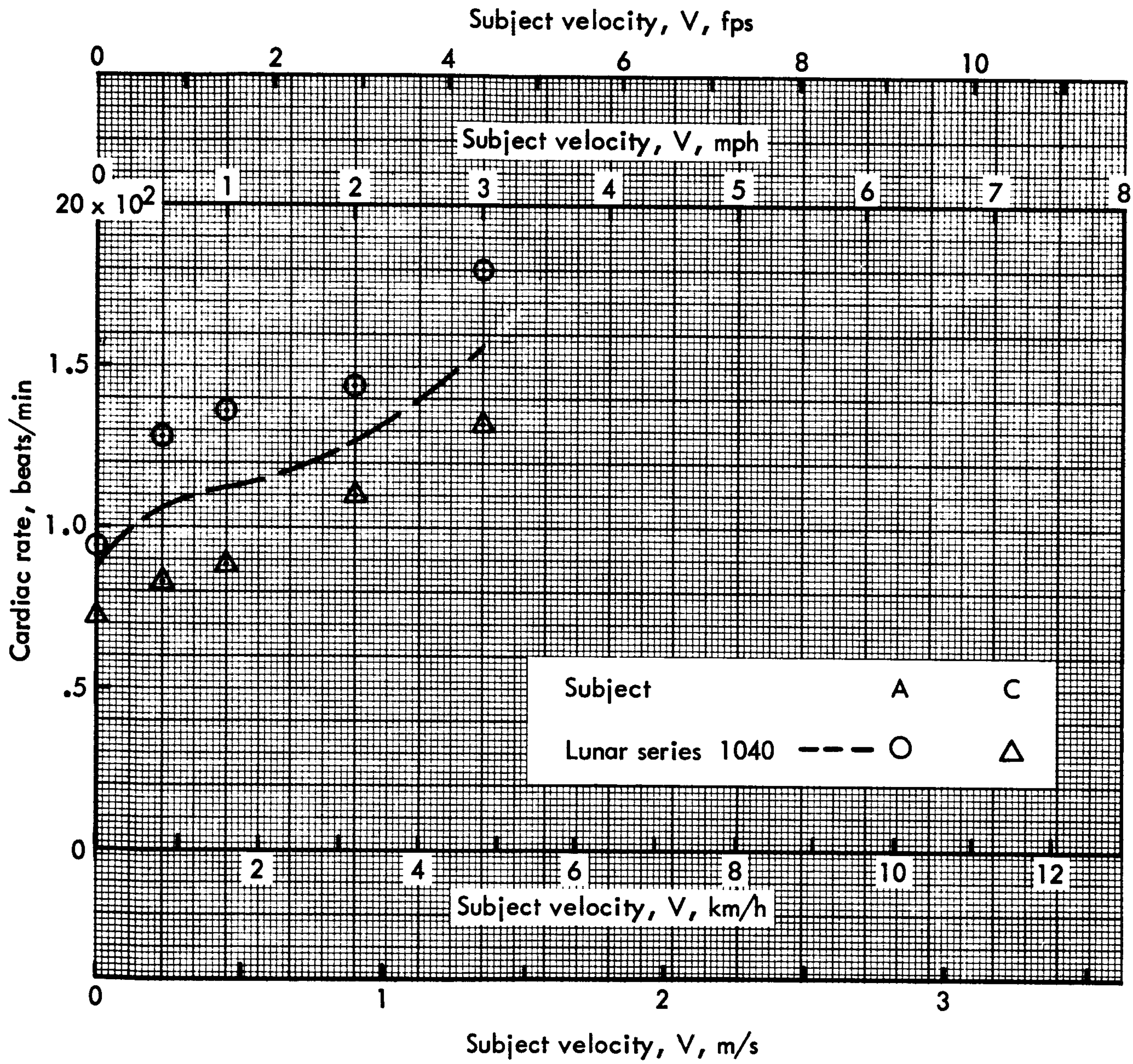


Figure 144. – Average cardiac rate versus subject velocity ascending at 30 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

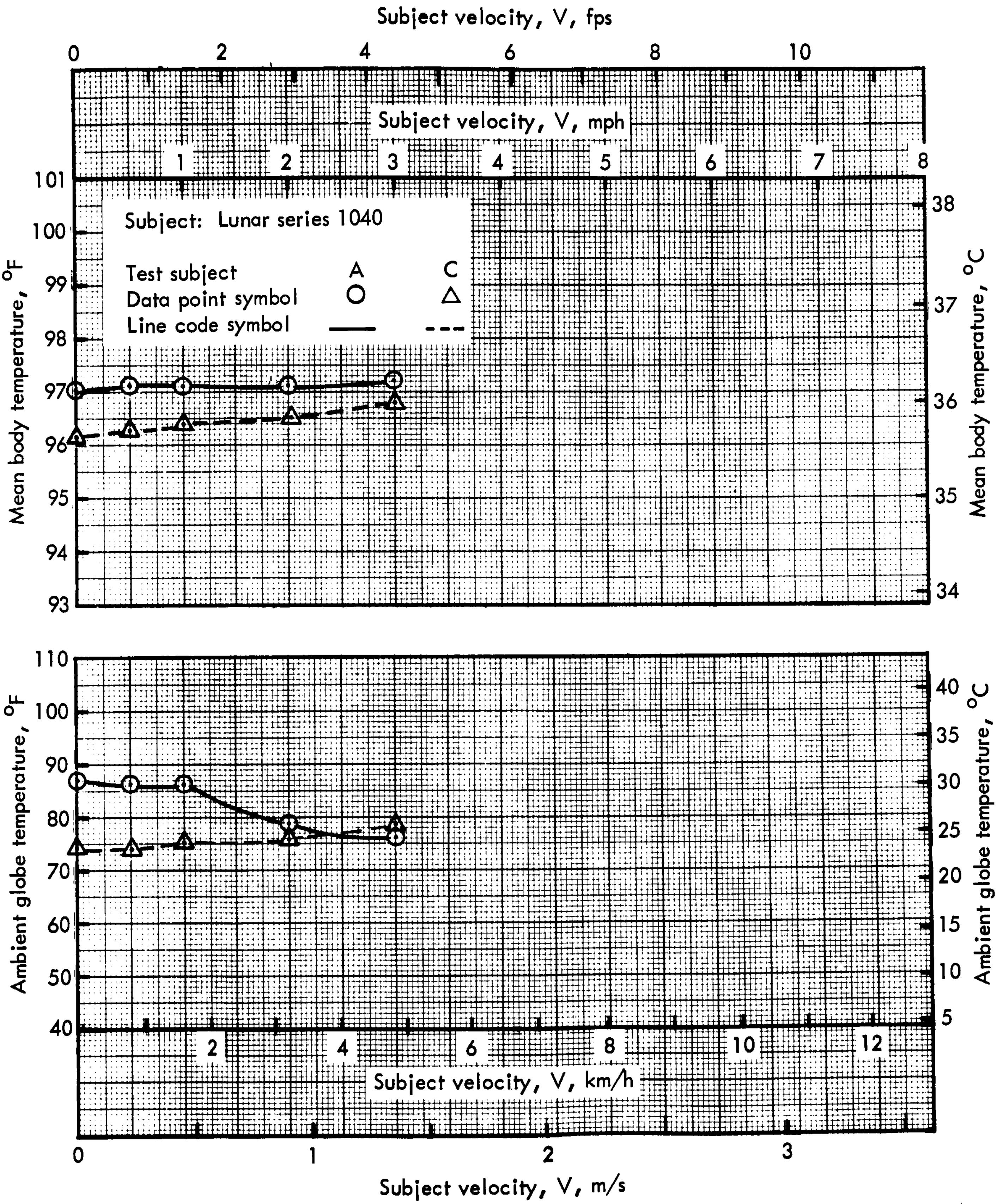


Figure 145. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity ascending at 30 degrees walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 1050

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking and running	Work Variable	descending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x*	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	8		5

Respiration, respiratory rate	Figure 146 *
respiratory volume expired	Figure 147
Metabolism, metabolic energy expenditure rate	Figure 148
metabolic energy expenditure rate per unit length	Figure 149
oxygen consumption	Figure 150
oxygen consumption per unit length	Figure 151
Cardiovascular function, cardiac rate	Figure 152 *
Body temperature, mean body temperature	Figure 153
Pressure suit environmental data	Not Obtained

Comments:

*No respiratory rate and cardiac rate was obtained for Subject C at 3.0 mph
Subject A only performed tests at 4.0 and 5.0 mph

*1/6 g treadmill speed limited to 5 mph.

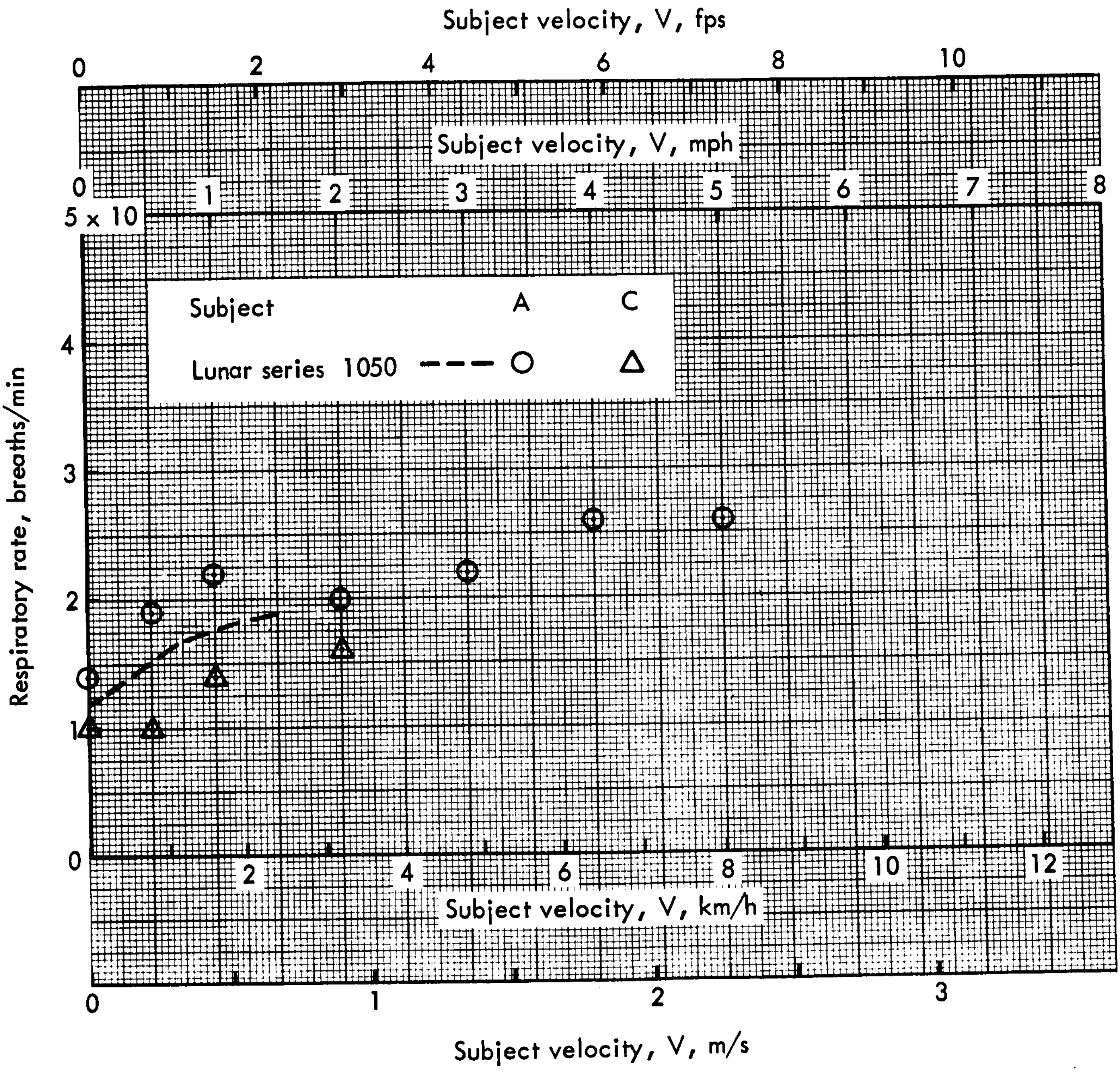


Figure 146. – Average respiratory rate versus subject velocity descending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

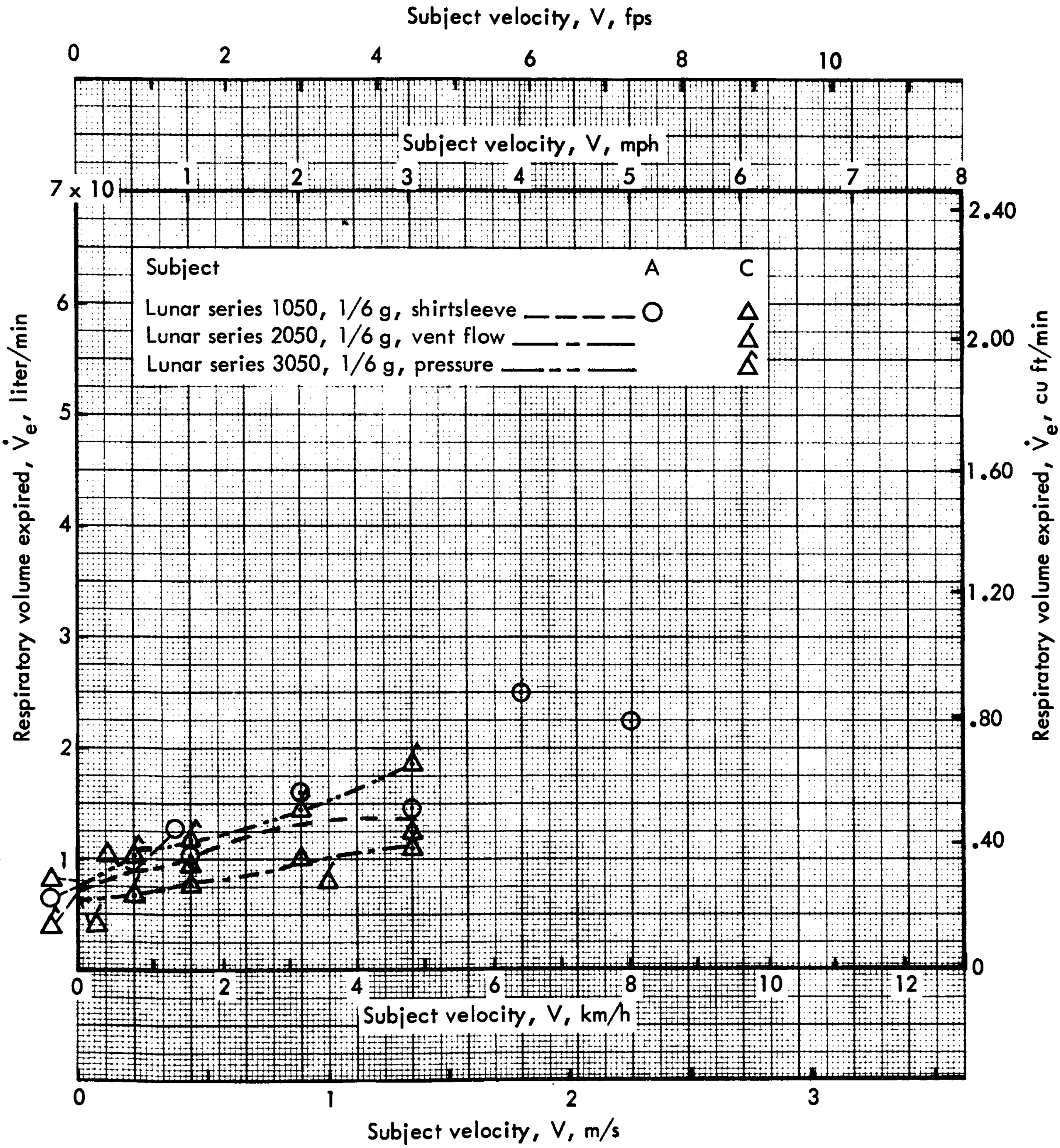


Figure 147. – Average mean respiratory volume versus subject velocity descending at 10 degrees walking and running.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

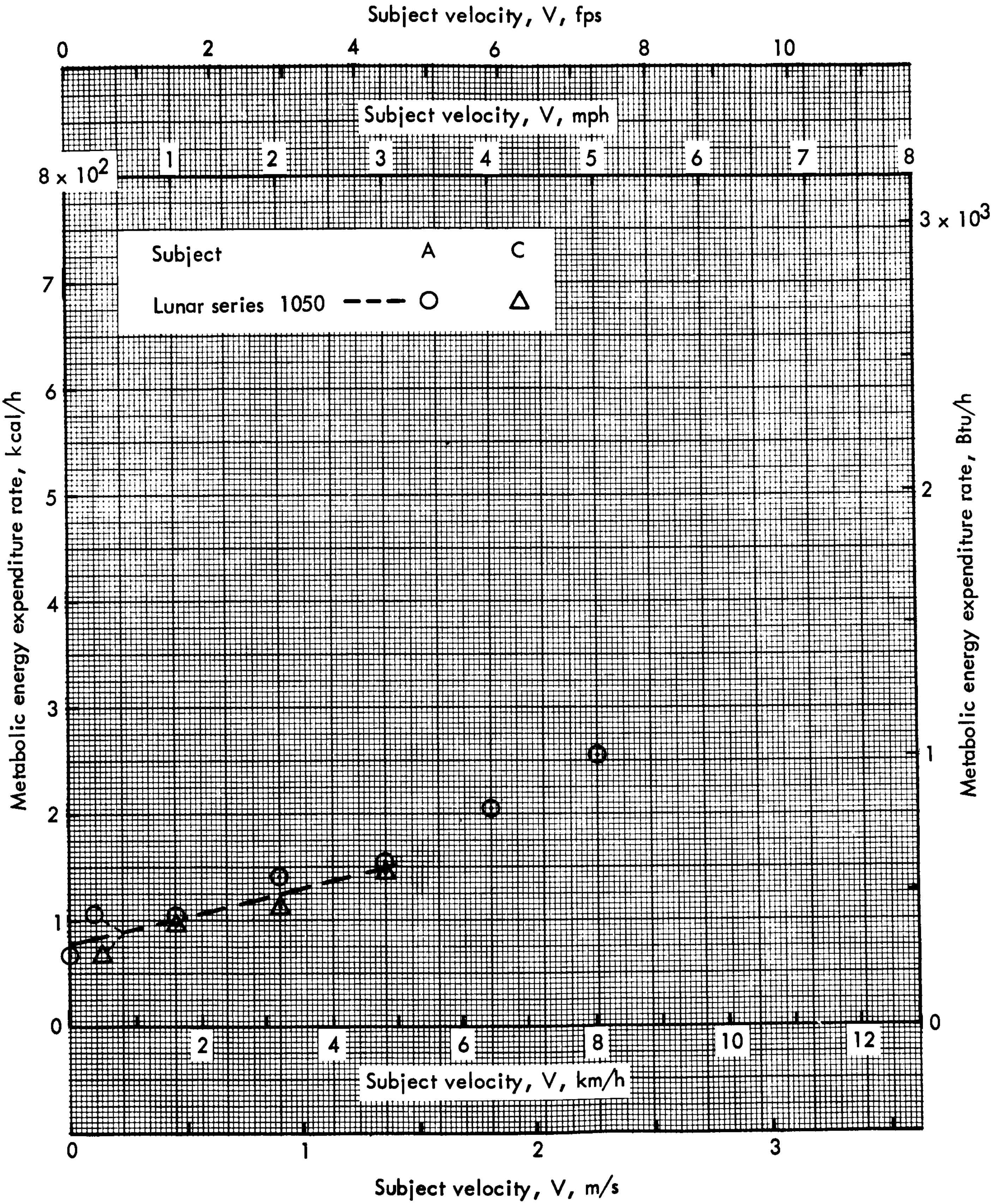


Figure 148. – Average metabolic energy expenditure rate versus subject velocity descending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

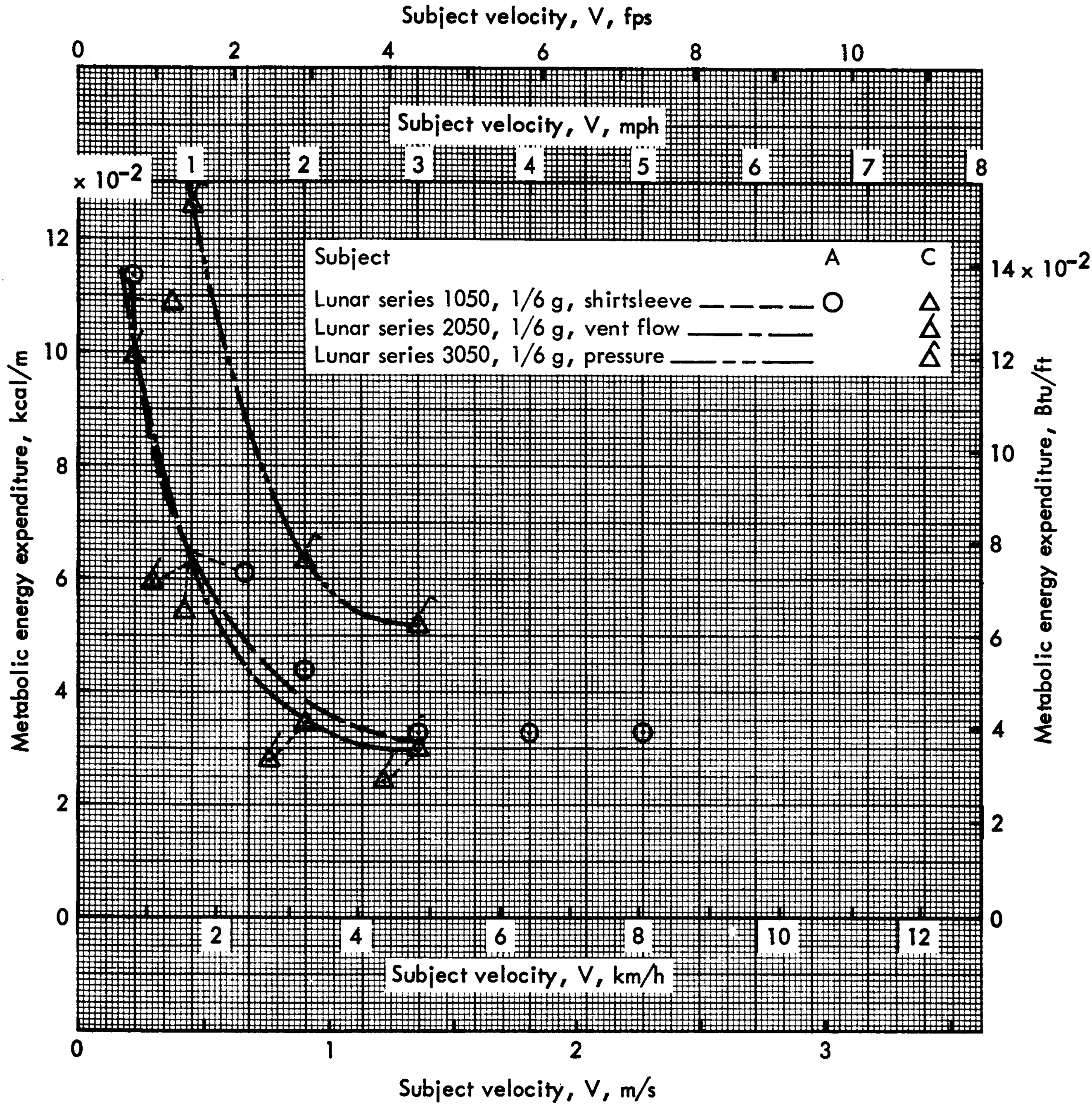


Figure 149. – Average metabolic energy expenditure per unit length versus subject velocity descending at 10 degrees walking and running. Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

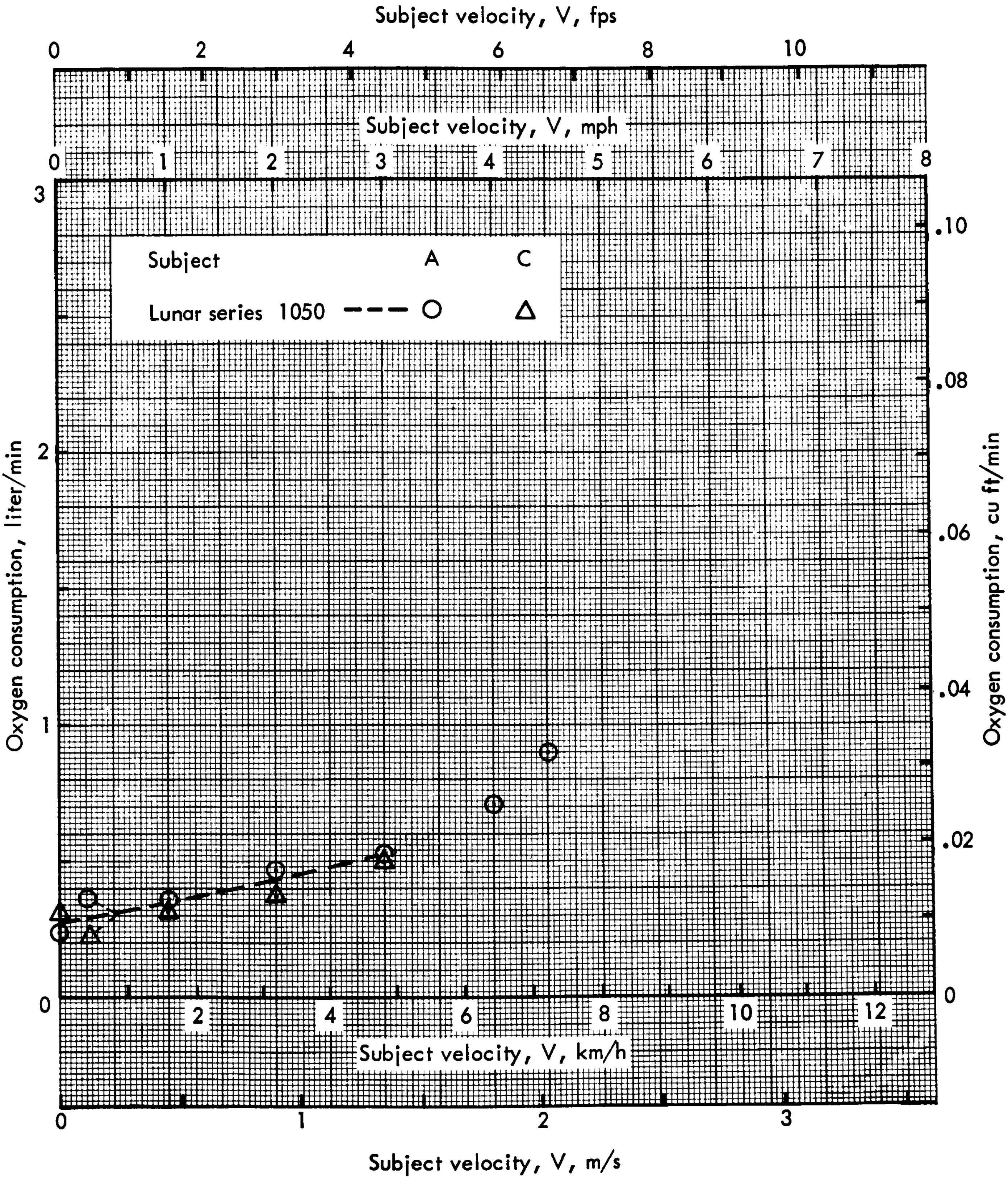


Figure 150. – Average oxygen consumption versus subject velocity descending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

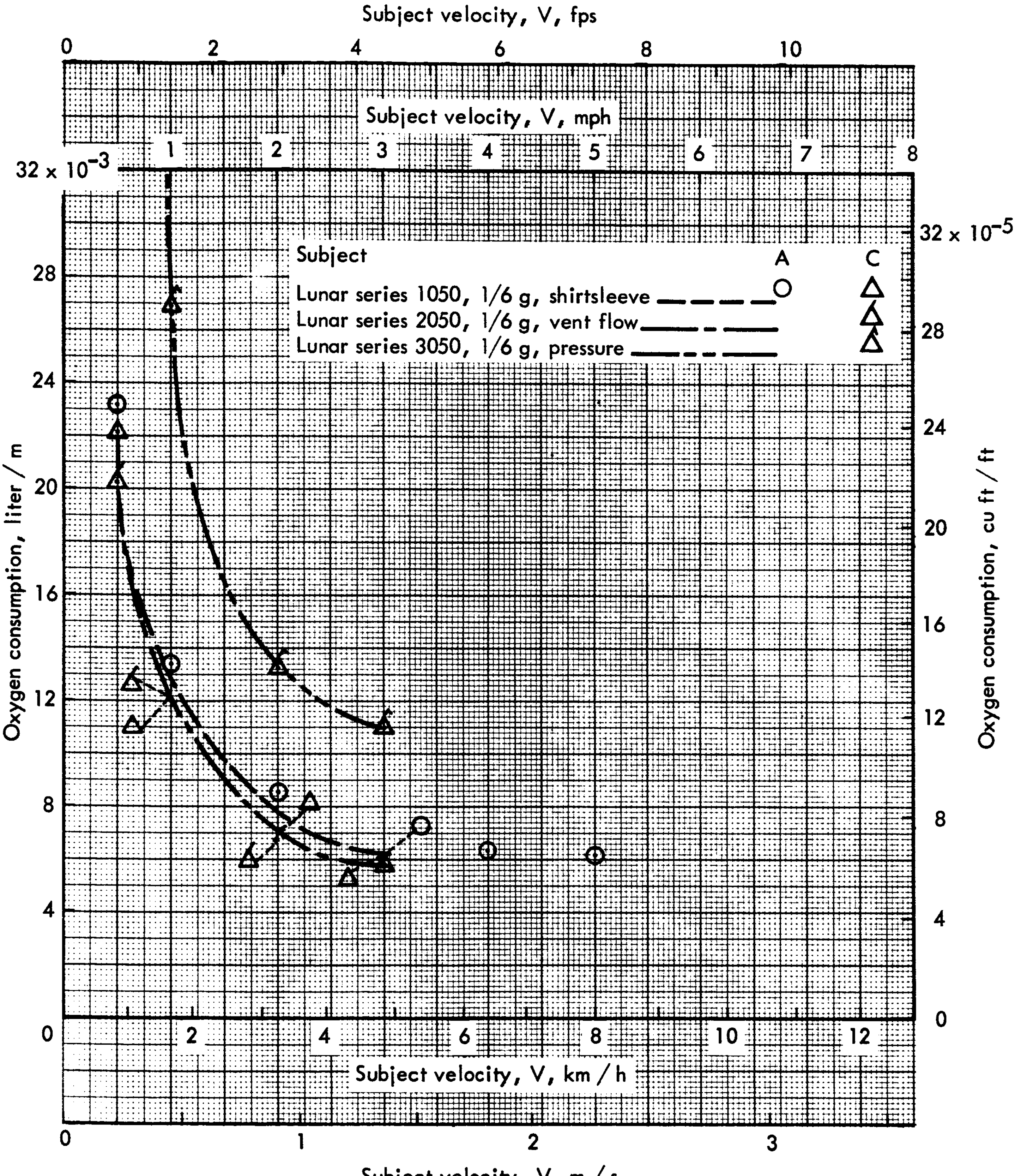


Figure 151. – Average oxygen consumption per unit length versus subject velocity descending at 10 degrees walking and running.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

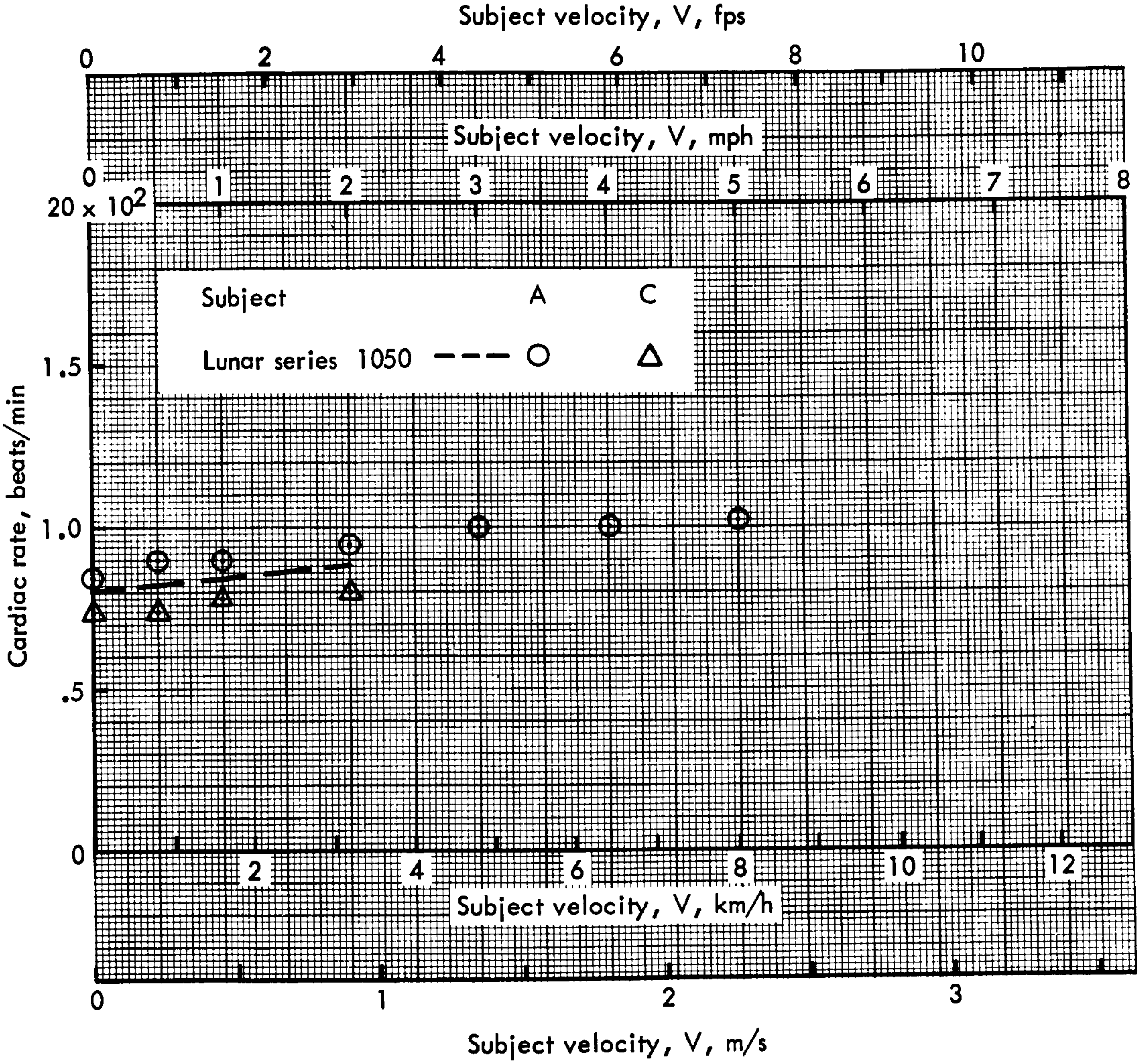


Figure 152. – Average cardiac rate versus subject velocity descending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

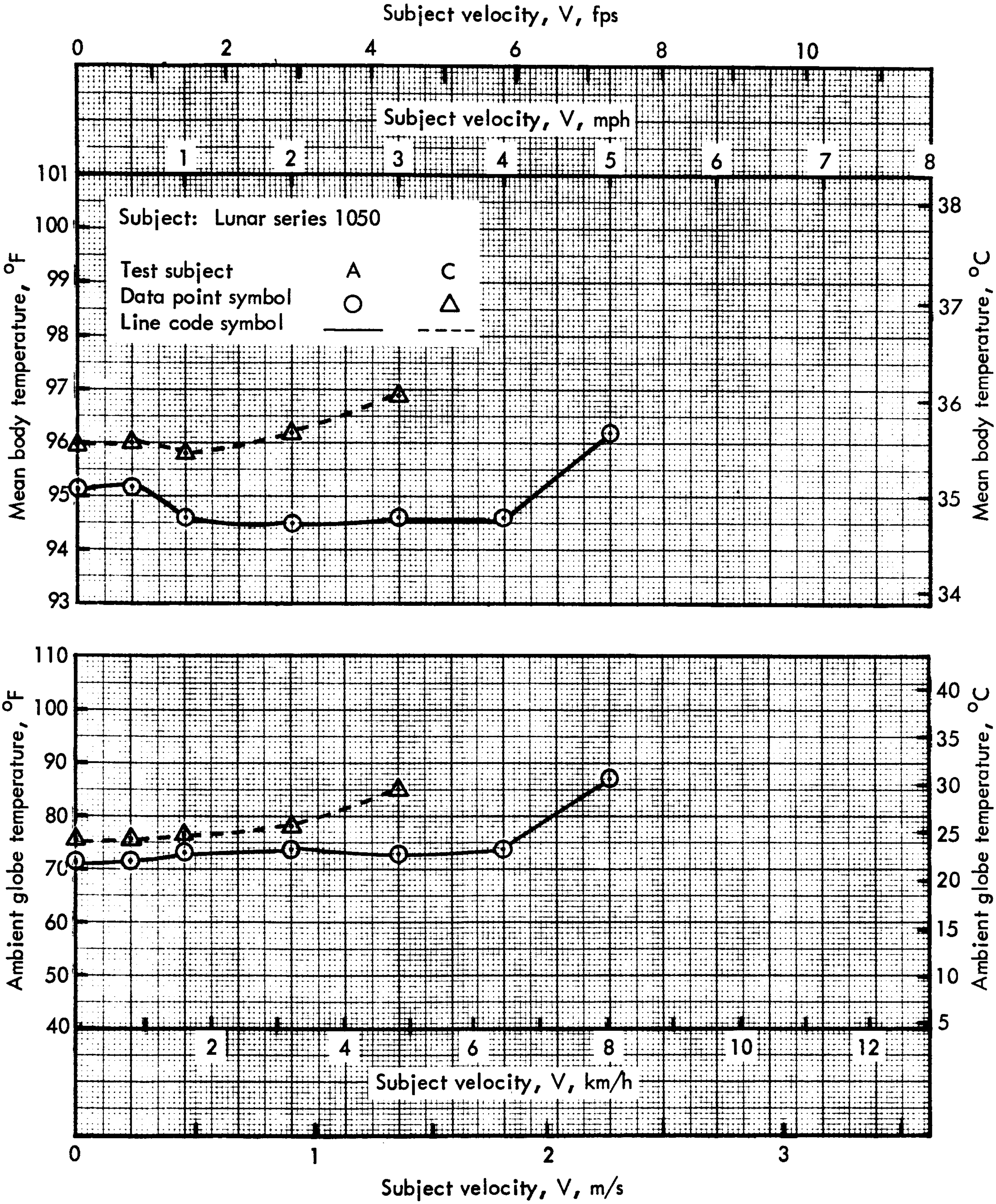


Figure 153. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity descending at 10 degrees walking and running.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2050

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	descending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			5

Respiration, respiratory rate	Figure 154*
respiratory volume expired	Figure 147
Metabolism, metabolic energy expenditure rate	Figure 155
metabolic energy expenditure rate per unit length	Figure 149
oxygen consumption	Figure 156
oxygen consumption per unit length	Figure 151
Cardiovascular function, cardiac rate	Figure 157**
Body temperature, mean body temperature	Figure 158
Pressure suit environmental data	Figure 159

Comments:

*No respiratory rate was obtained for Subject C at 1.0 mph

**No cardiac rate was obtained for Subject C at 1.0 thru 3.0 mph

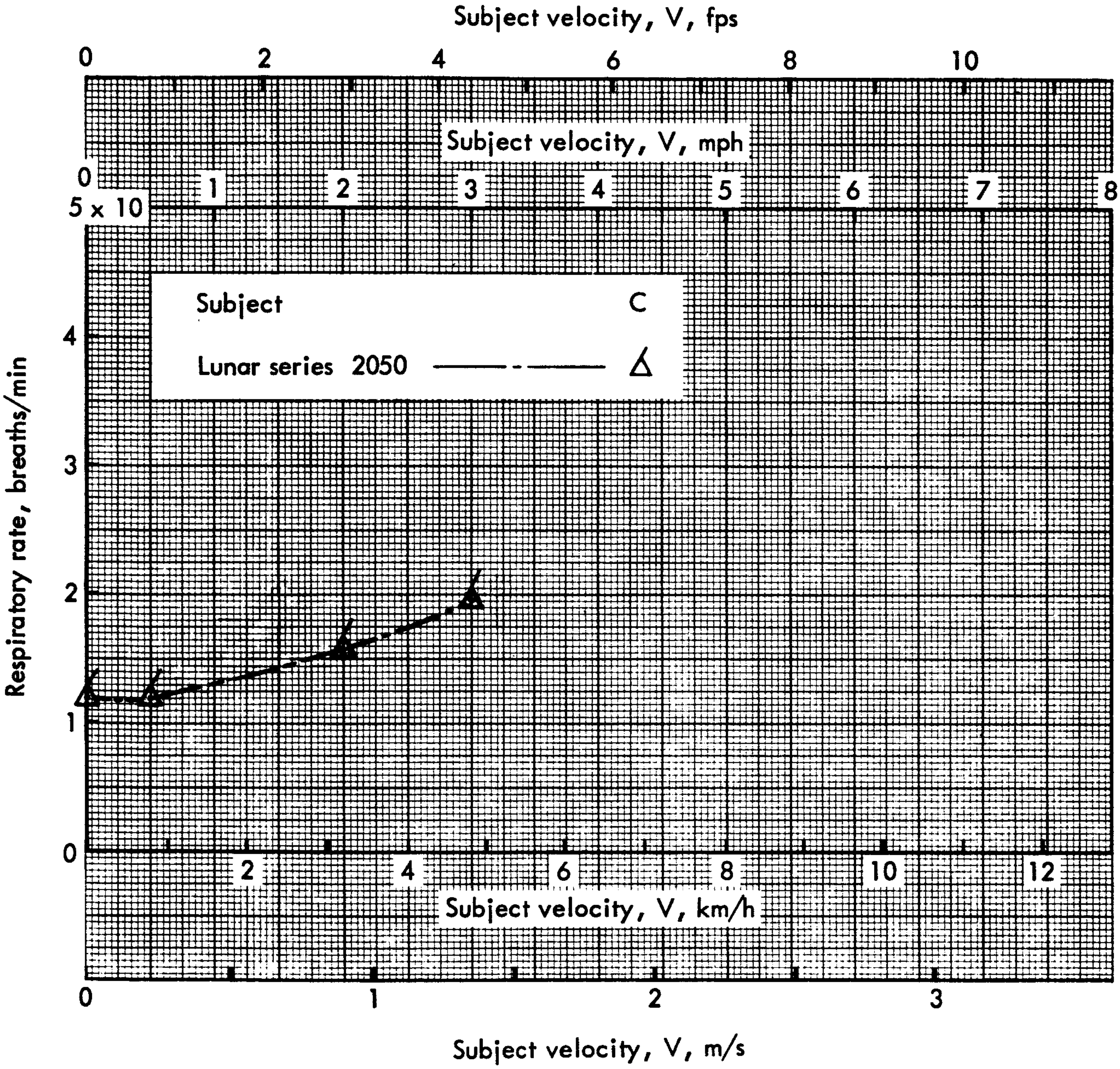


Figure 154. – Respiratory rate versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

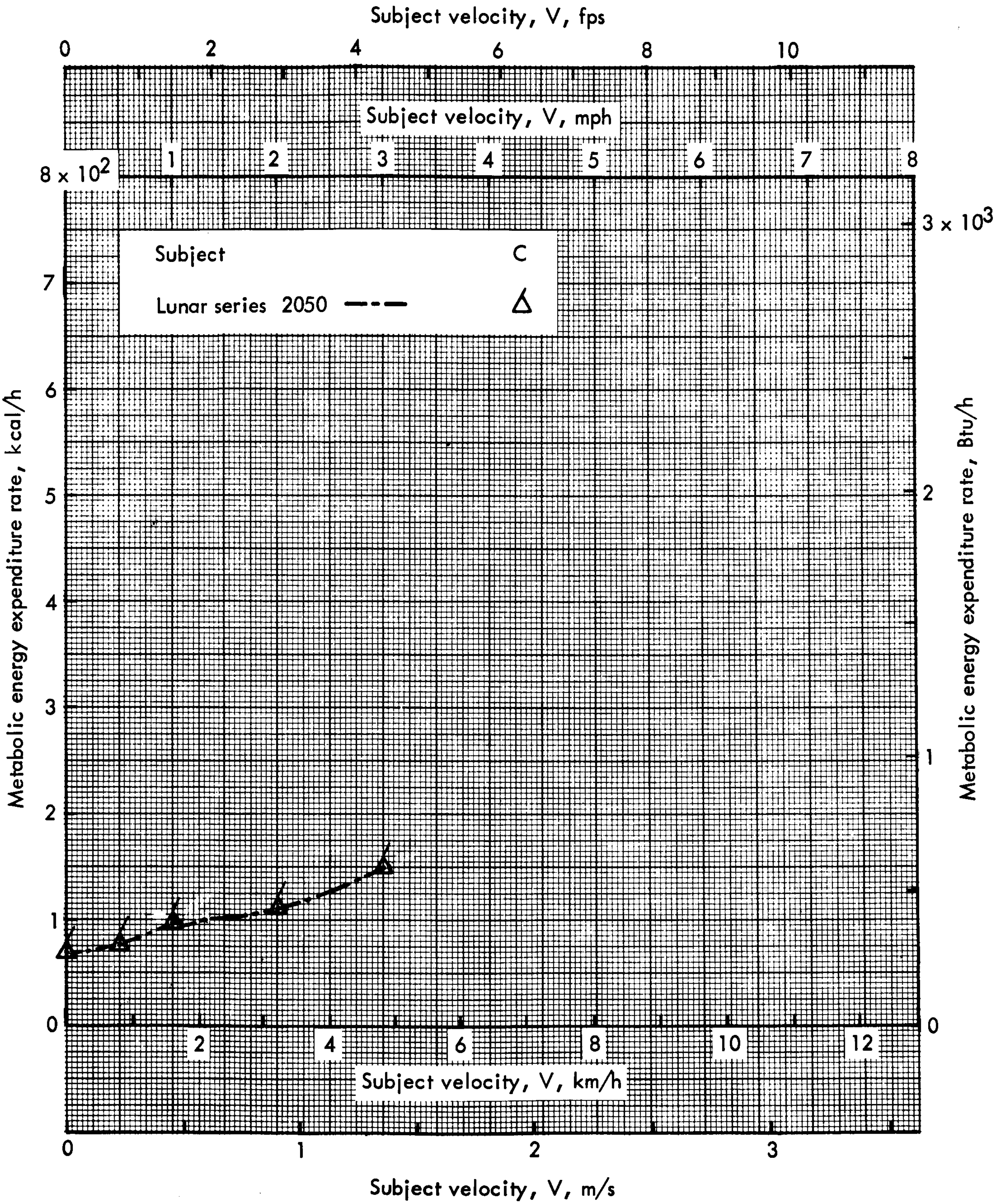


Figure 155. – Metabolic energy expenditure rate versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

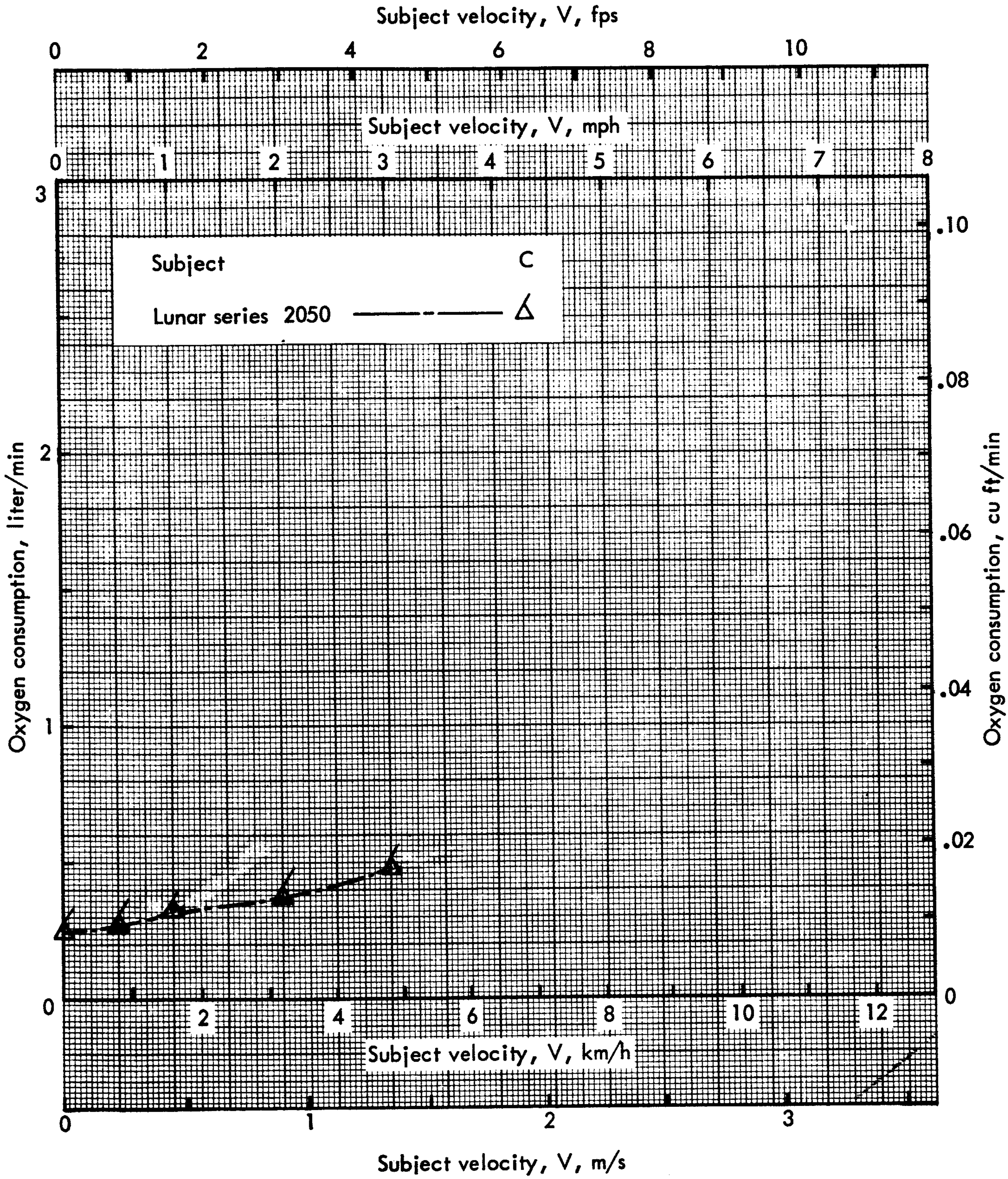


Figure 156. – Oxygen consumption versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

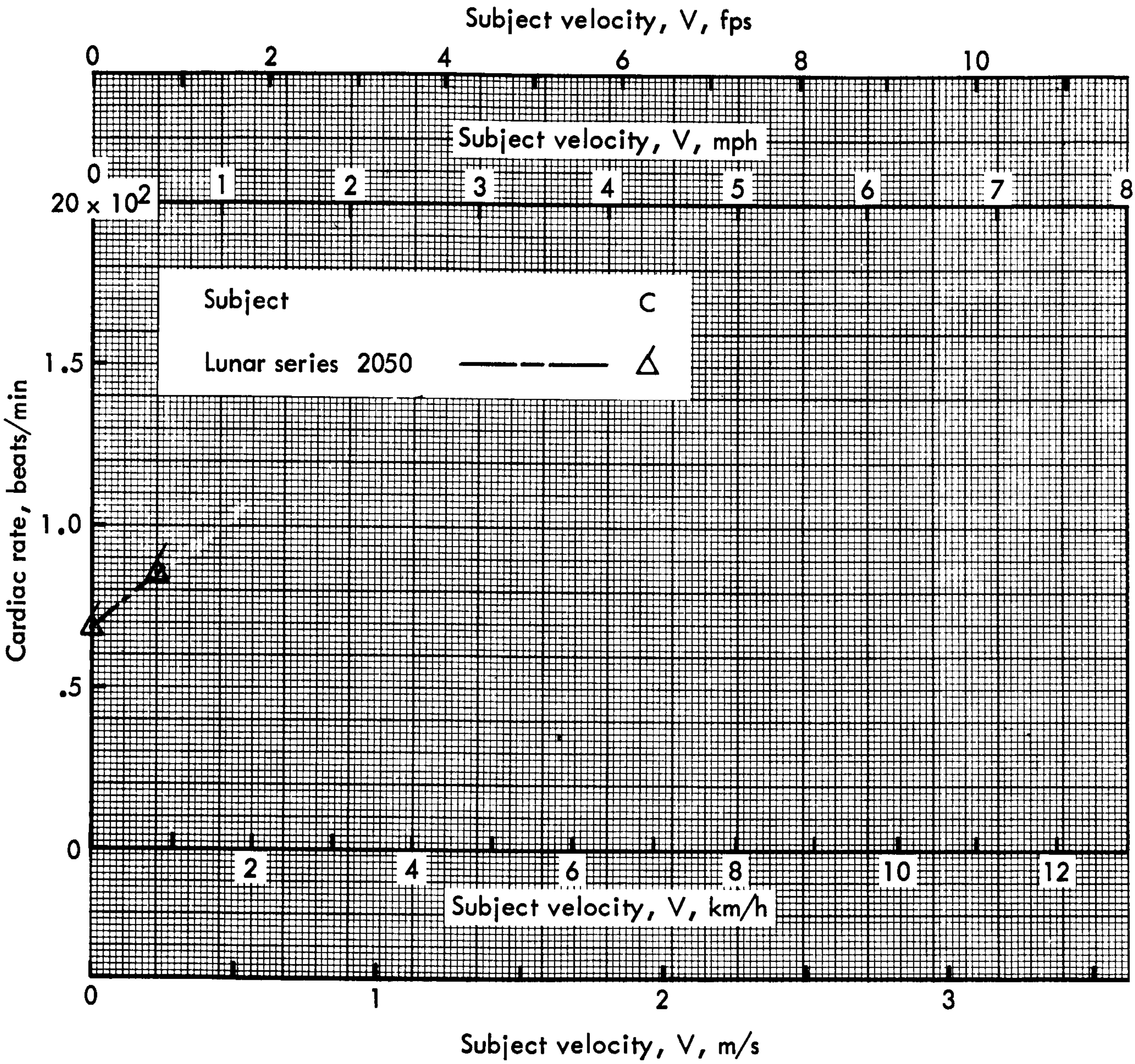


Figure 157. – Cardiac rate versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

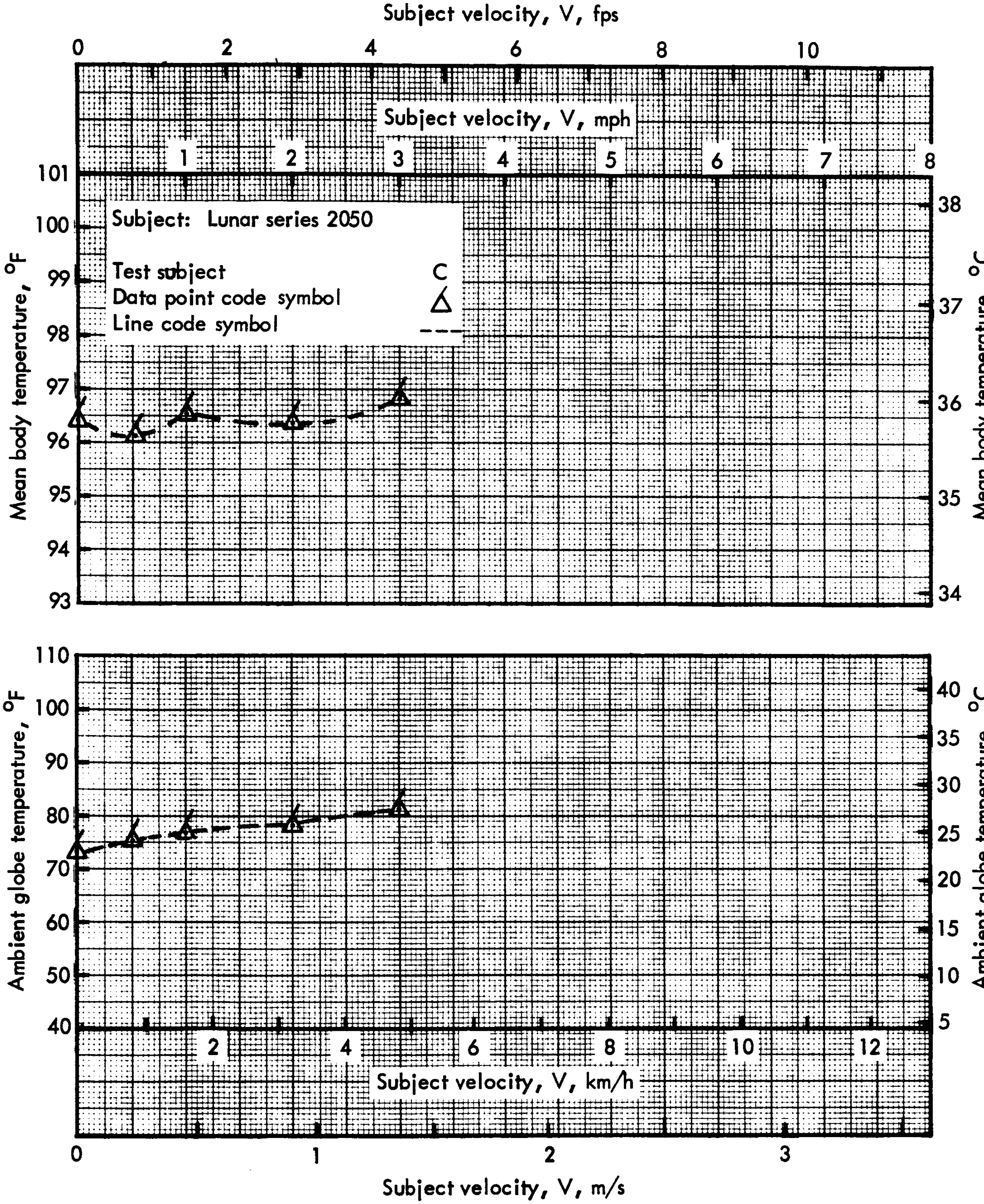


Figure 158. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

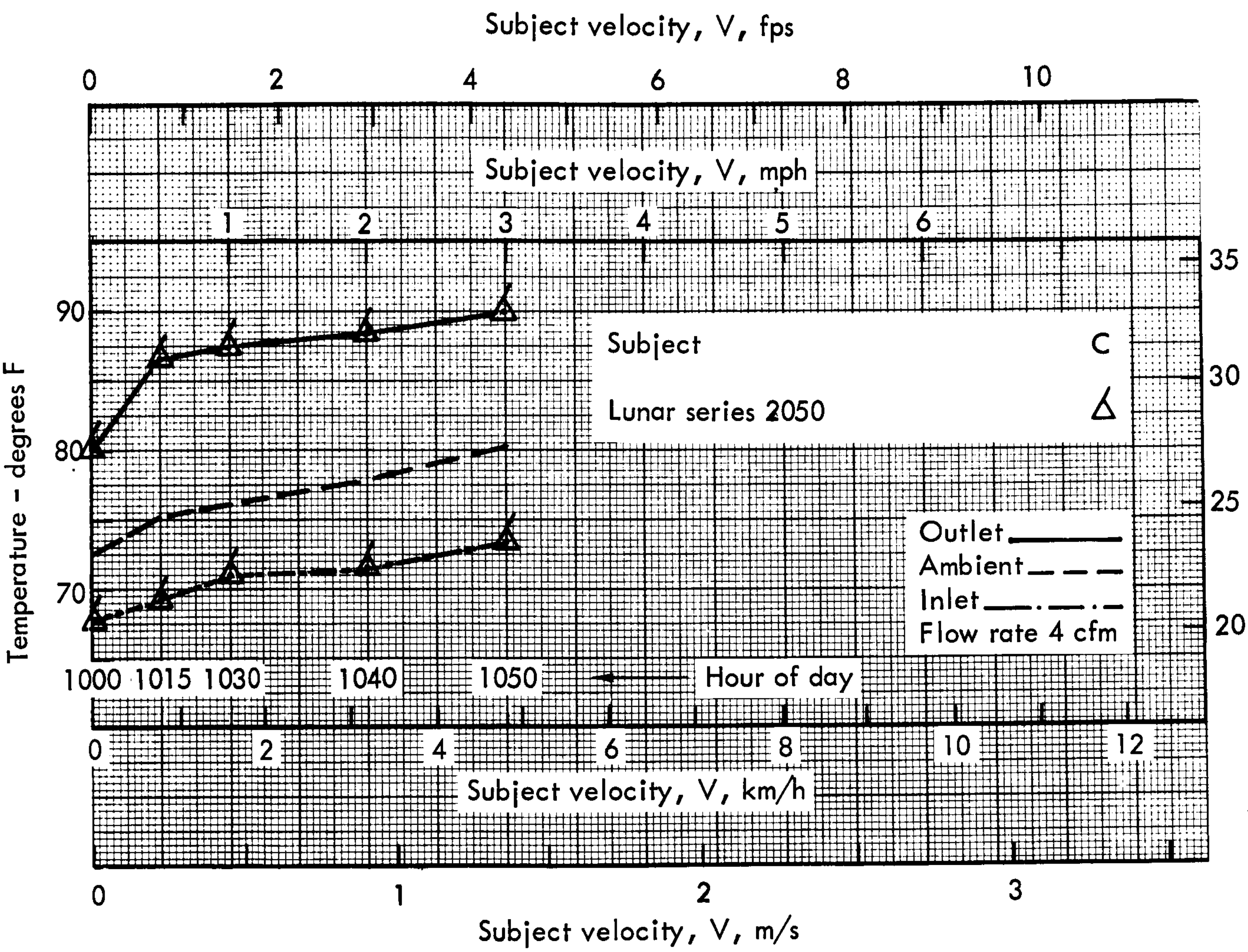


Figure 159. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3050

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	walking	Work Variable	descending at 10°
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			5

Respiration, respiratory rate	Figure 160
respiratory volume expired	Figure 147
Metabolism, metabolic energy expenditure rate	Figure 161
metabolic energy expenditure rate per unit length	Figure 149
oxygen consumption	Figure 162
oxygen consumption per unit length	Figure 151
Cardiovascular function, cardiac rate	Figure 163
Body temperature, mean body temperature	Figure 164
Pressure suit environmental data	Figure 165

Comments:

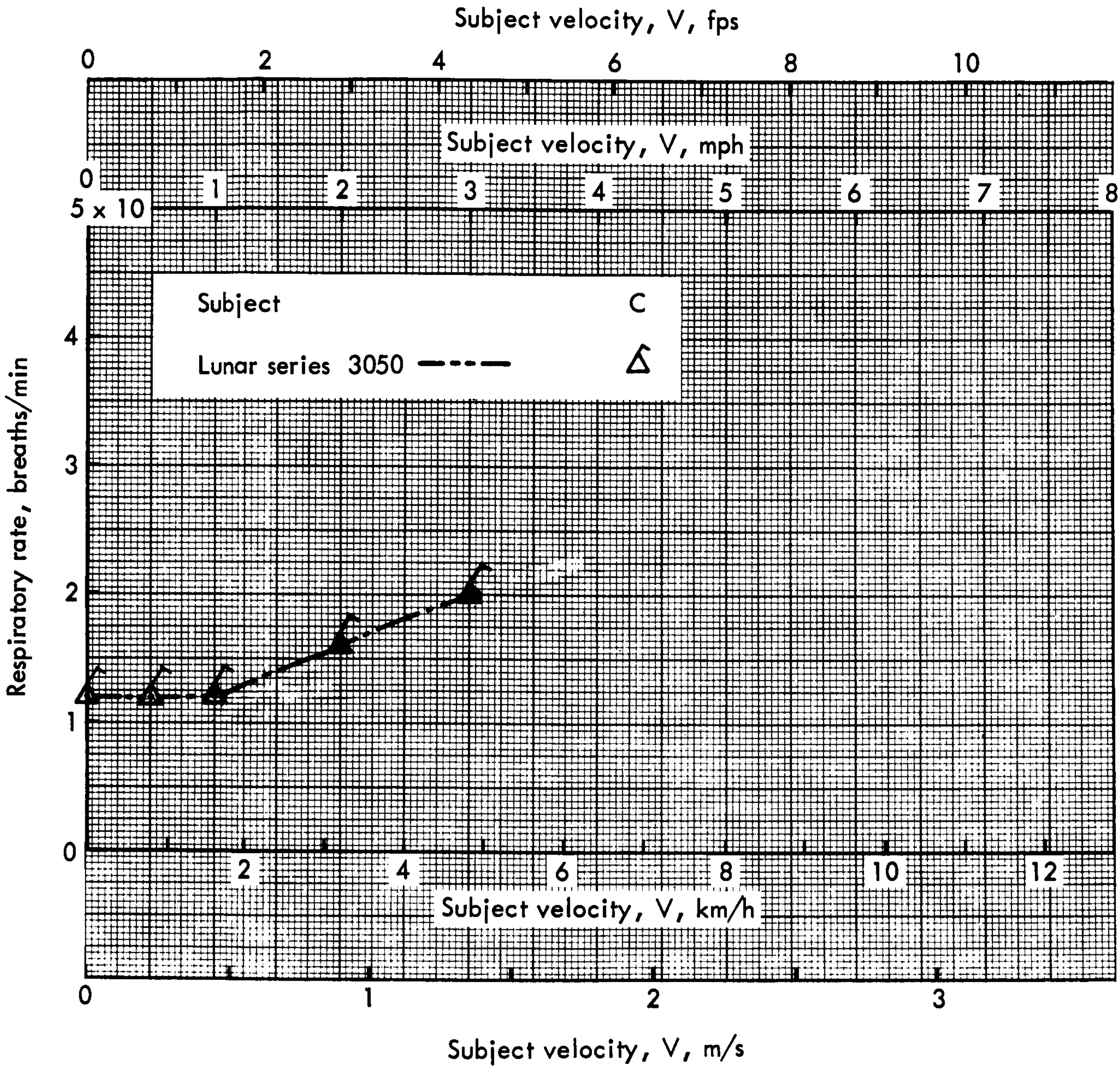


Figure 160. – Respiratory rate versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

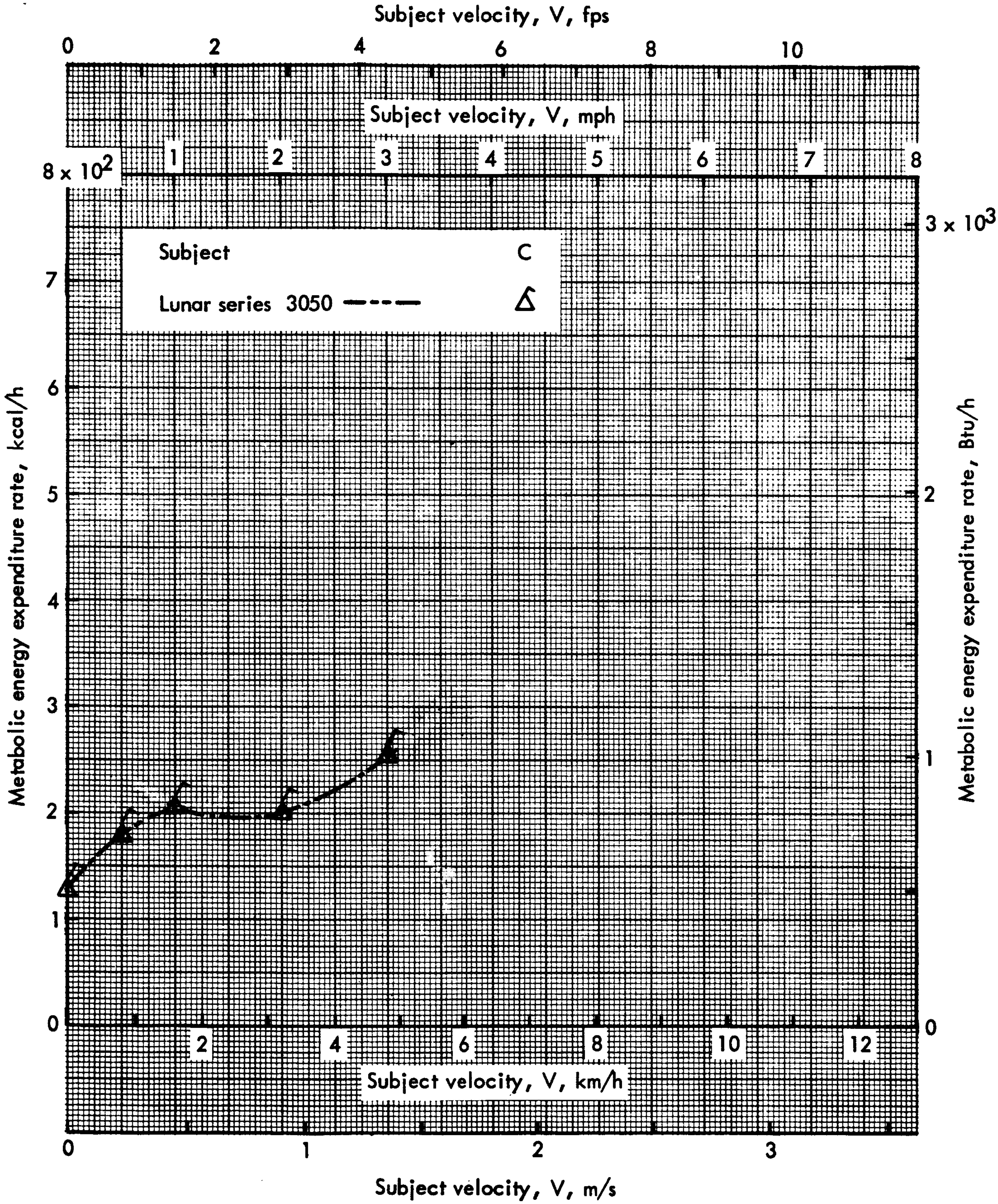


Figure 161. – Metabolic energy expenditure rate versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

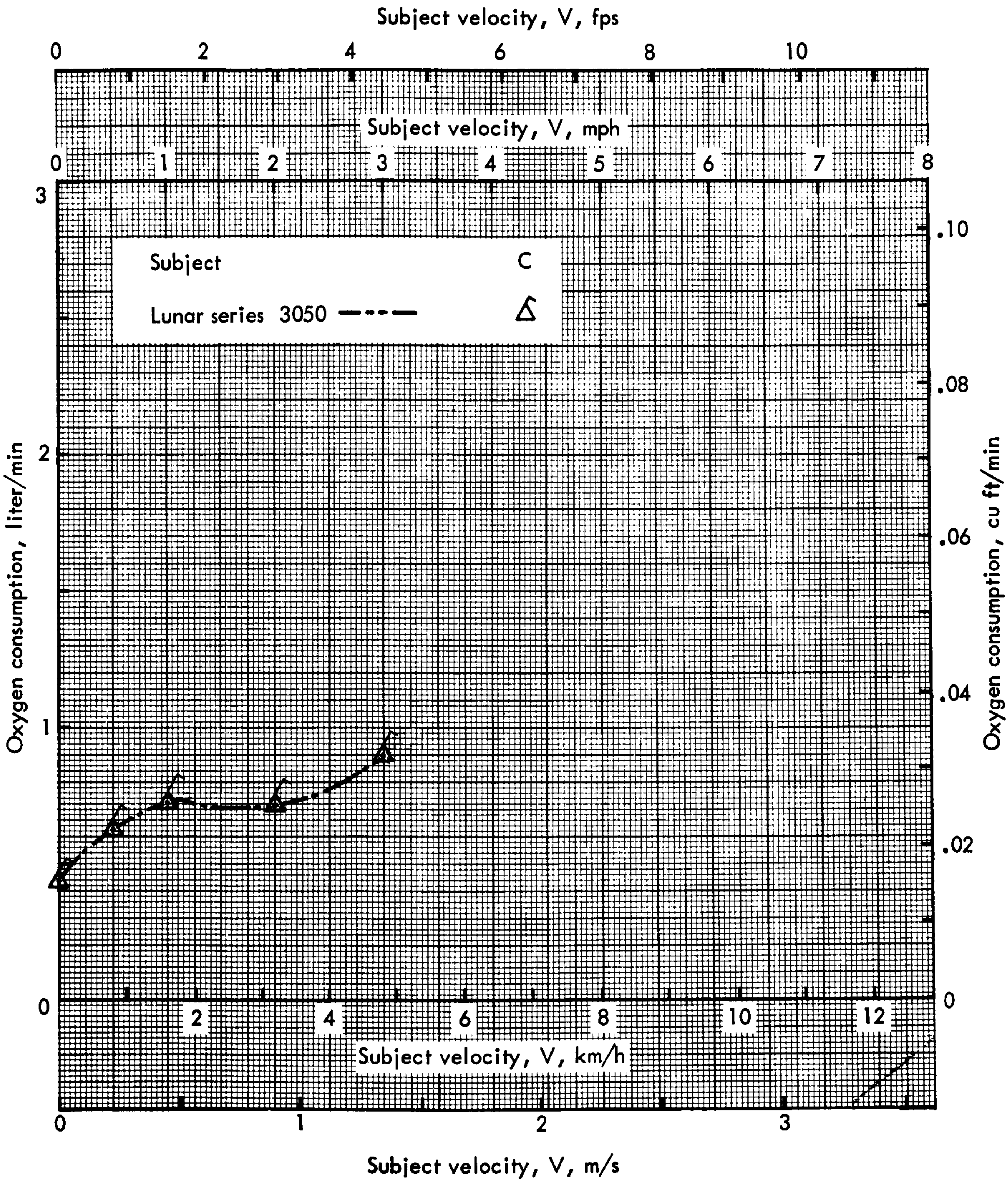


Figure 162. – Oxygen consumption versus subject velocity descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

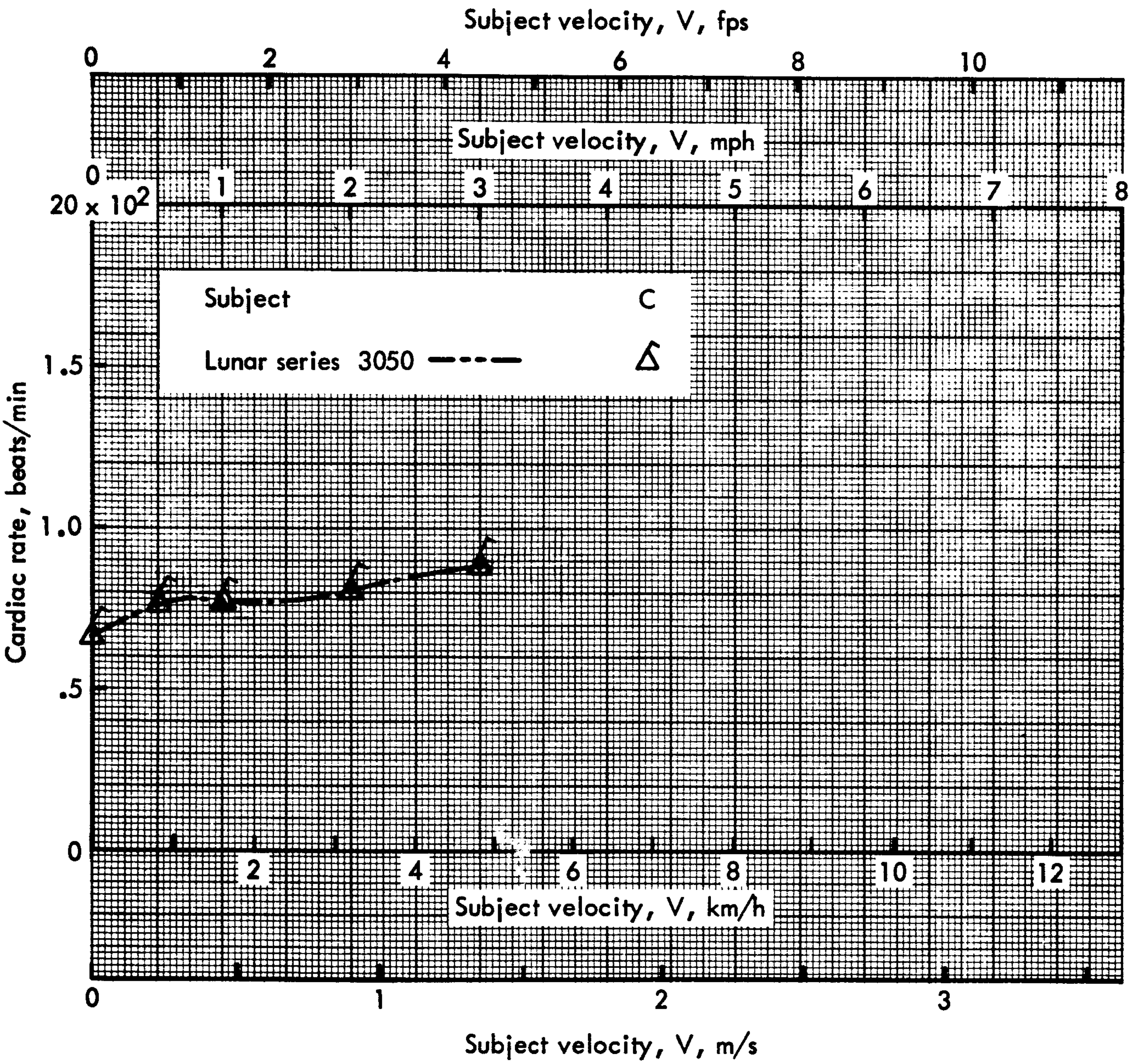


Figure 163. – Cardiac rate versus subject velocity descending at 10 degrees walking.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

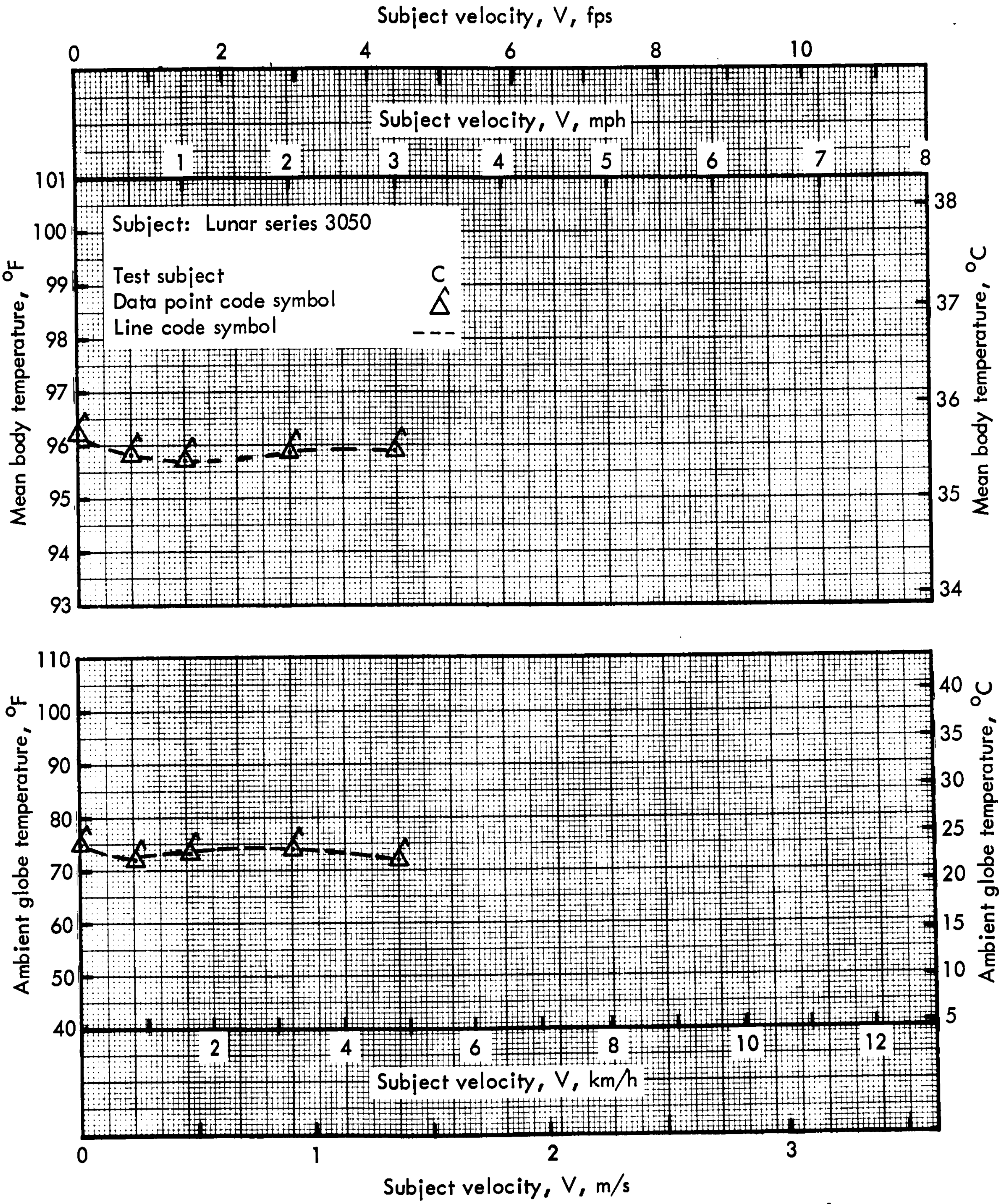


Figure 164. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity descending at 10 degrees walking.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

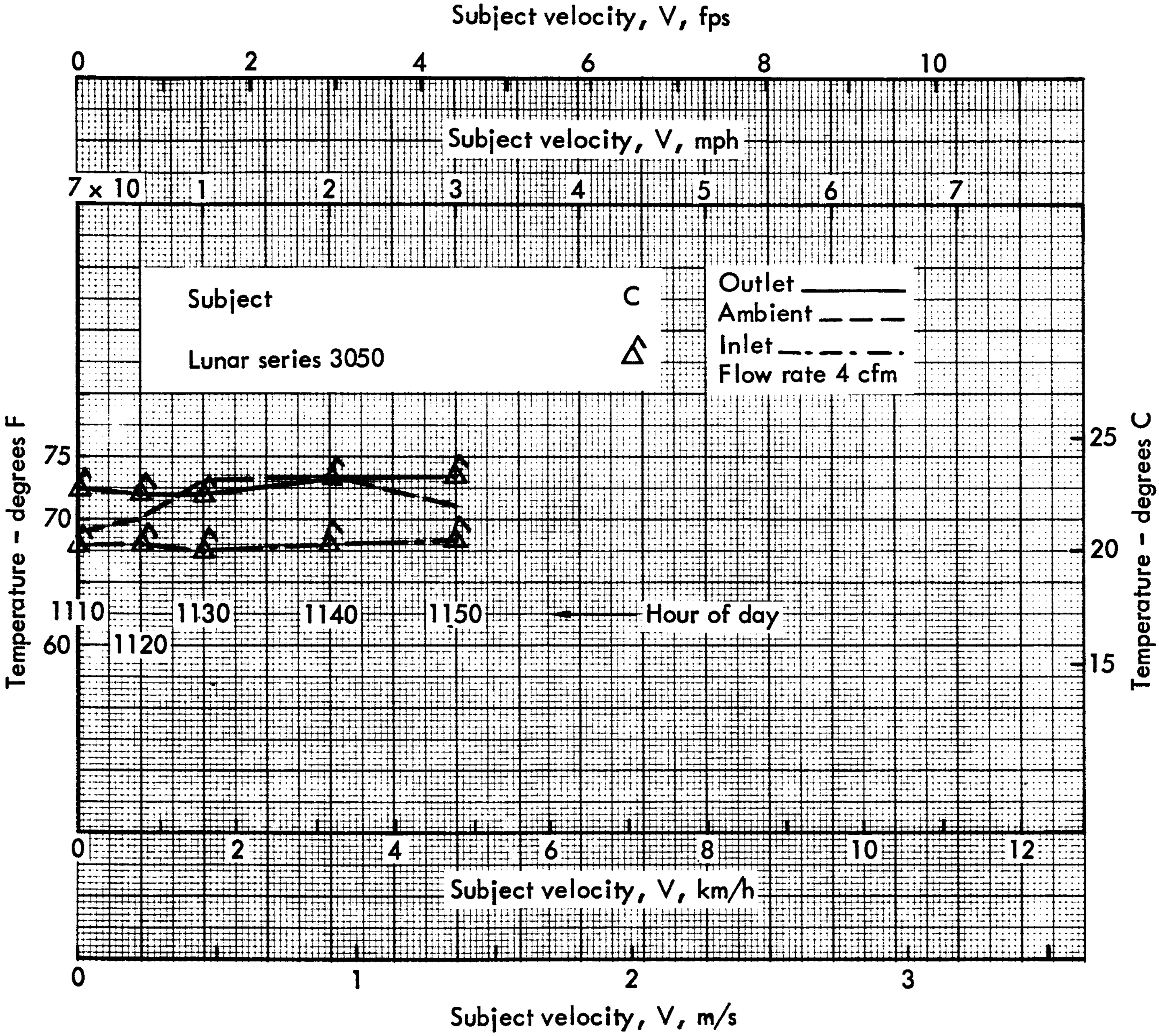


Figure 165. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, descending at 10 degrees walking.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series 1060

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	walking	Work Variable	descending at 20^{o}
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x*	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	3		3

Respiration, respiratory rate	Figure 166 **
respiratory volume expired	Figure 167
Metabolism, metabolic energy expenditure rate	Figure 168
metabolic energy expenditure rate per unit length	Figure 169
oxygen consumption	Figure 170
oxygen consumption per unit length	Figure 171
Cardiovascular function, cardiac rate	Figure 172
Body temperature, mean body temperature	Figure 173
Pressure suit environmental data	Not obtained

Comments:

*1/6 g treadmill speed limited to 2 mph

**The respiratory rate of Subject A at 2 mph appears to be incorrect

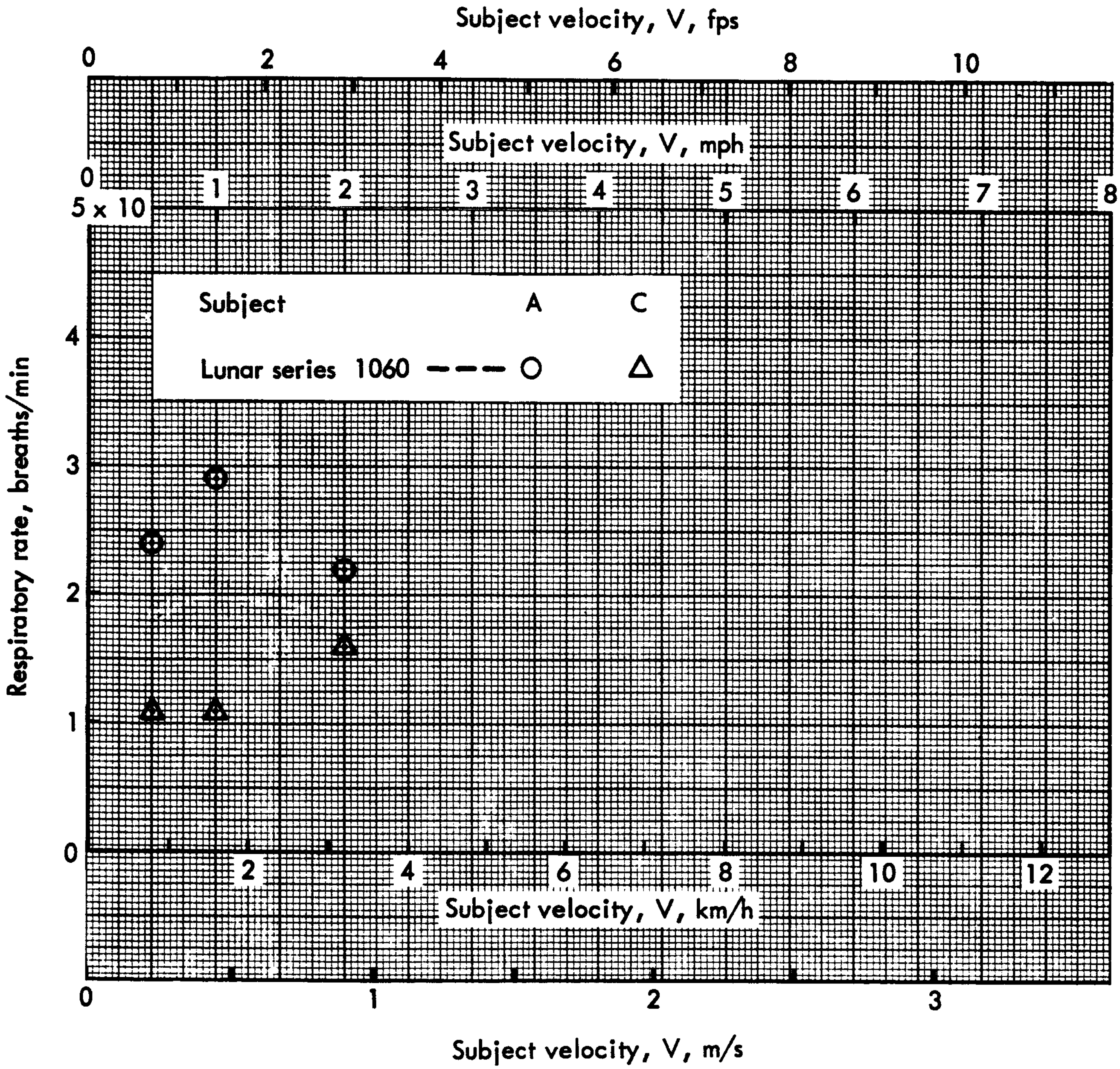


Figure 166. – Average respiratory rate versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

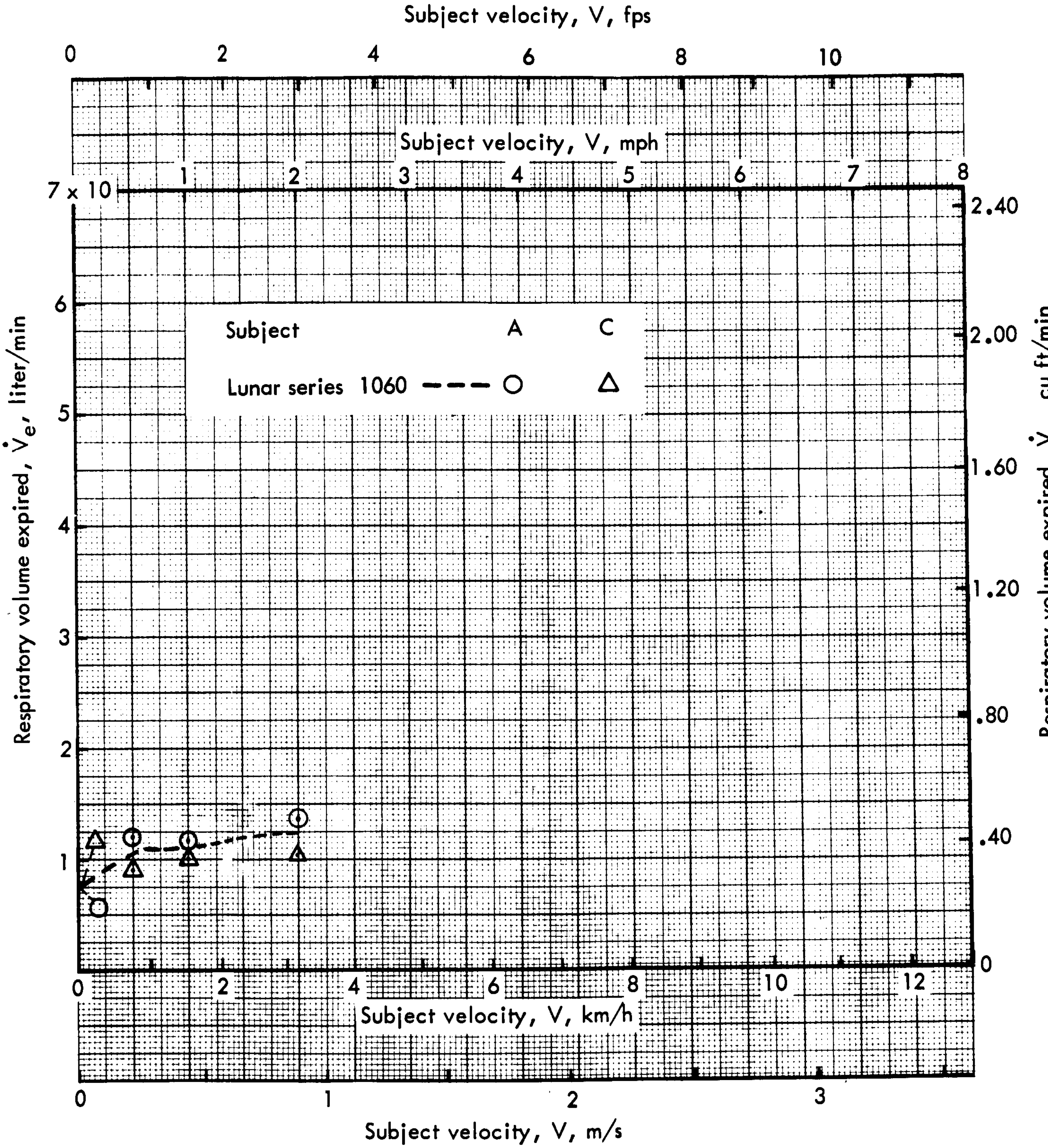


Figure 167. – Average mean respiratory volume versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

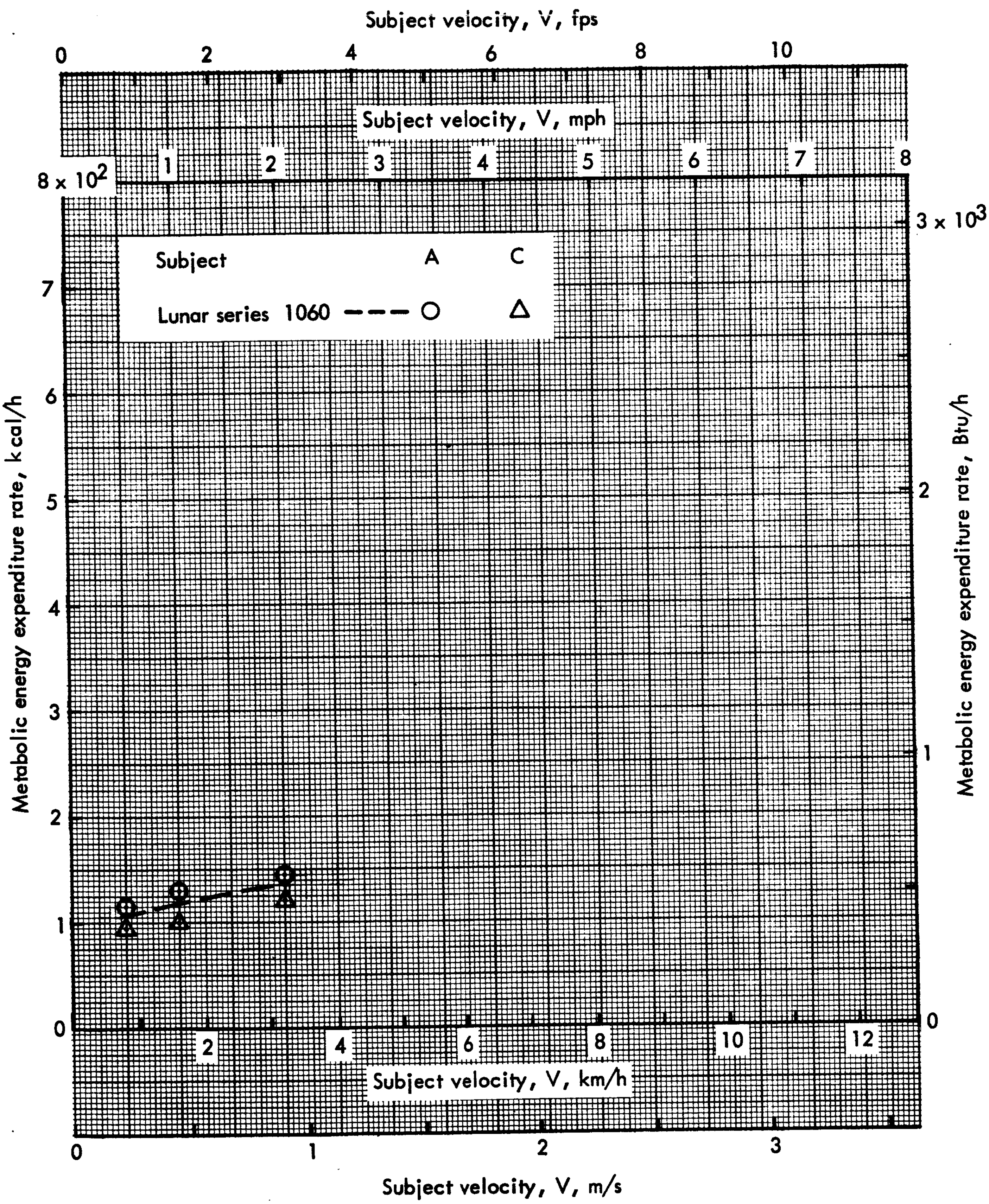


Figure 168. – Average metabolic energy expenditure rate versus subject velocity descending at 20 degrees walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

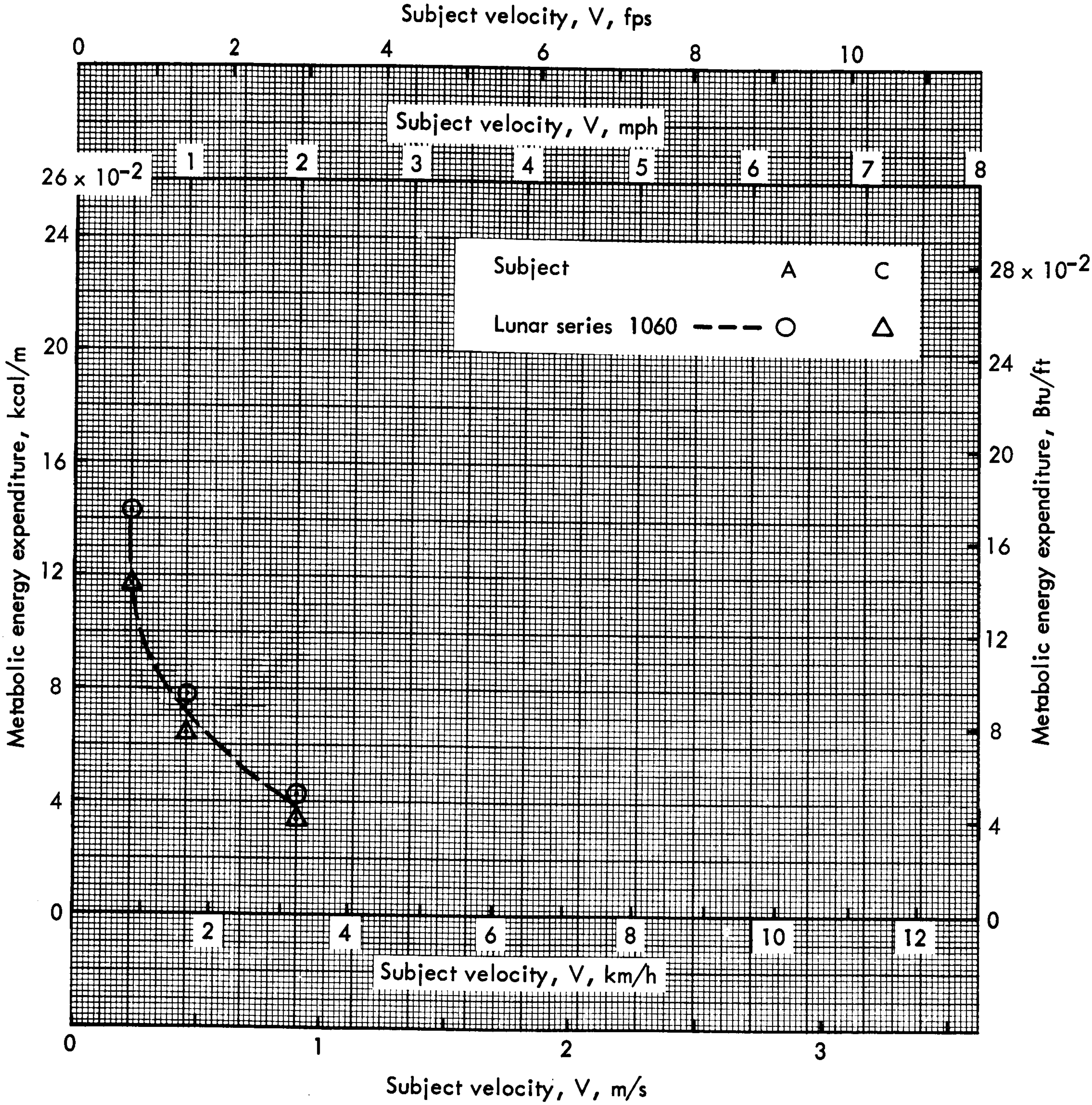


Figure 169. – Average metabolic energy expenditure per unit length versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

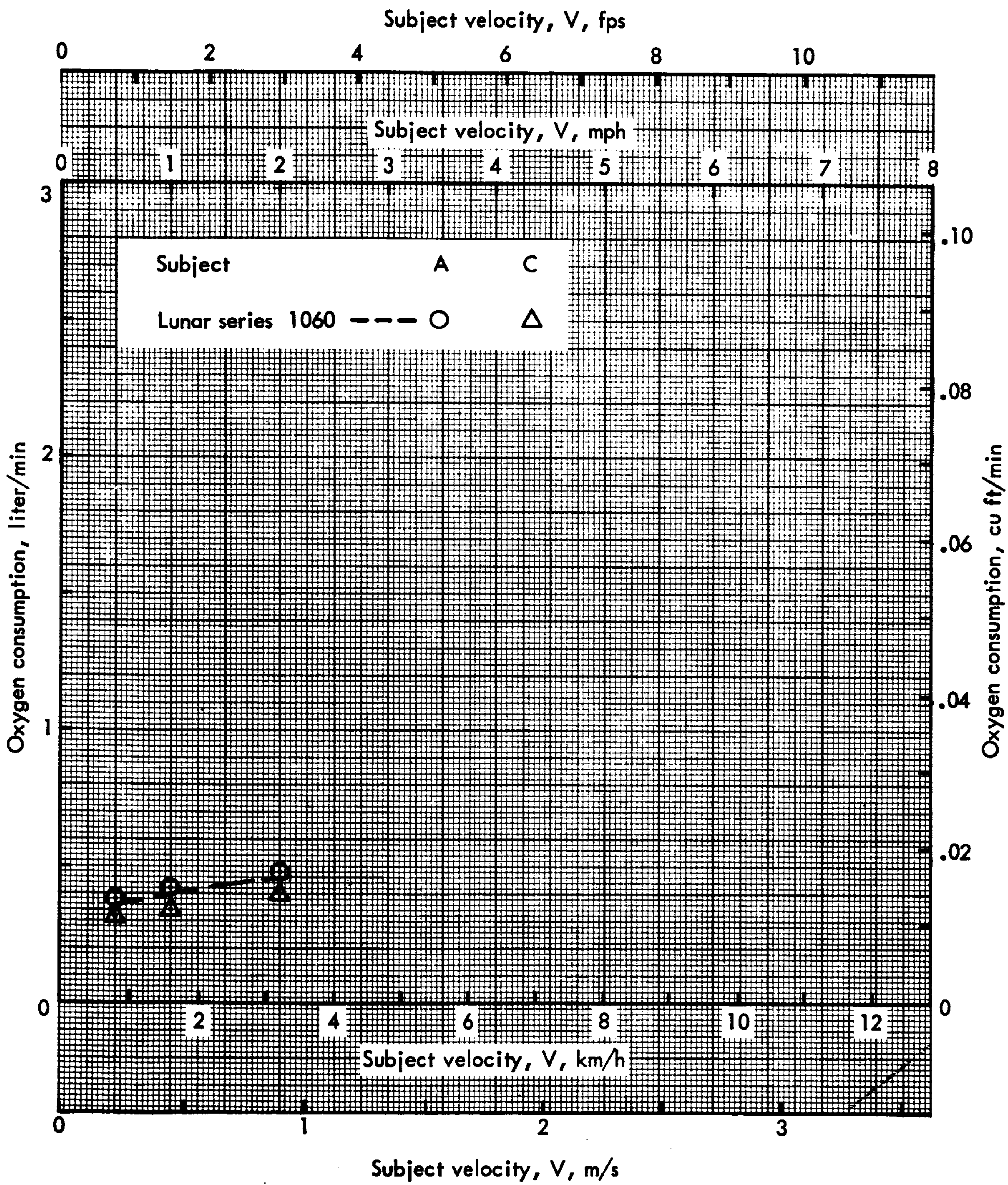


Figure 170. – Average oxygen consumption versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

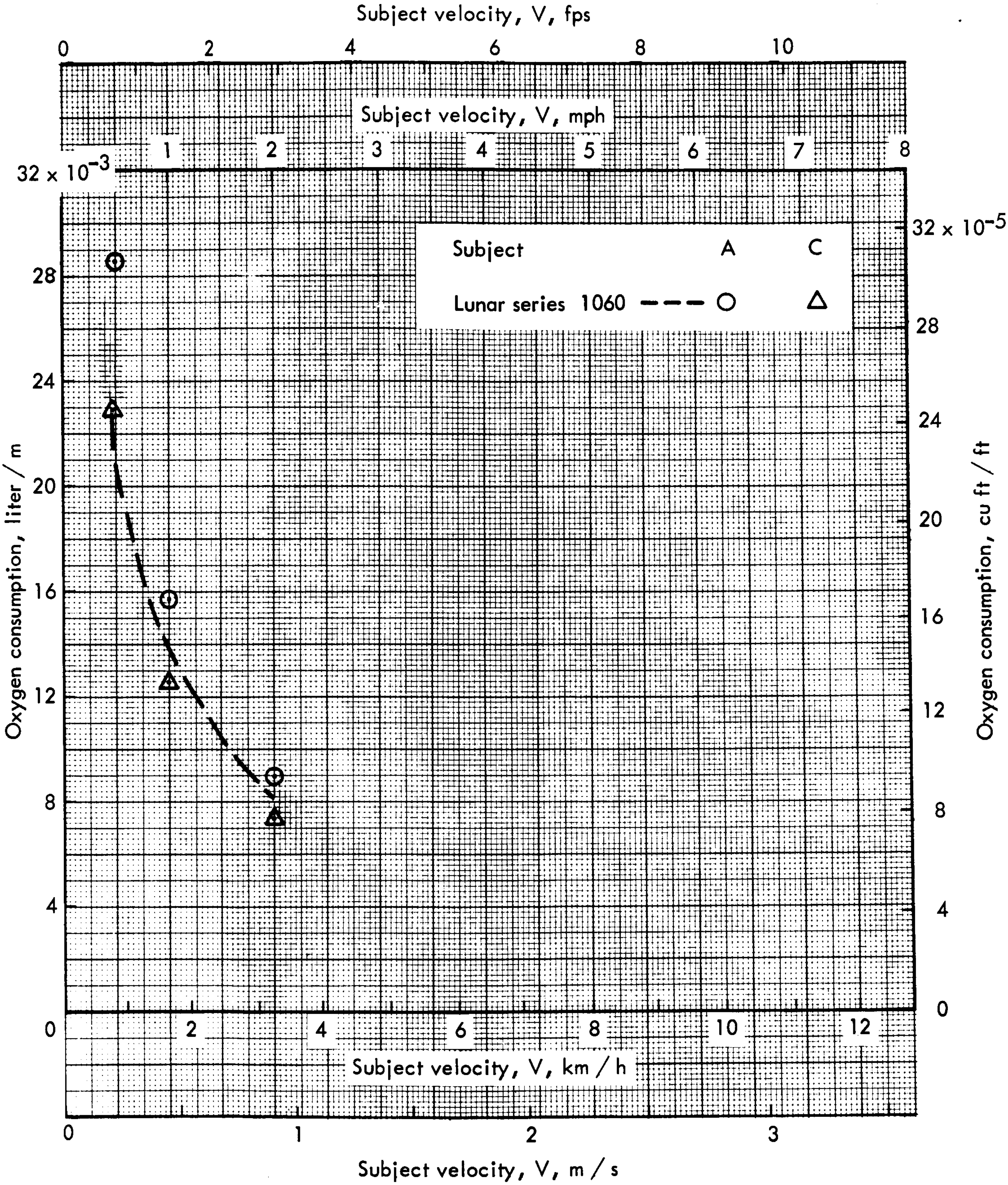


Figure 171. – Average oxygen consumption per unit length versus subject velocity descending at 20 degrèes walking.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

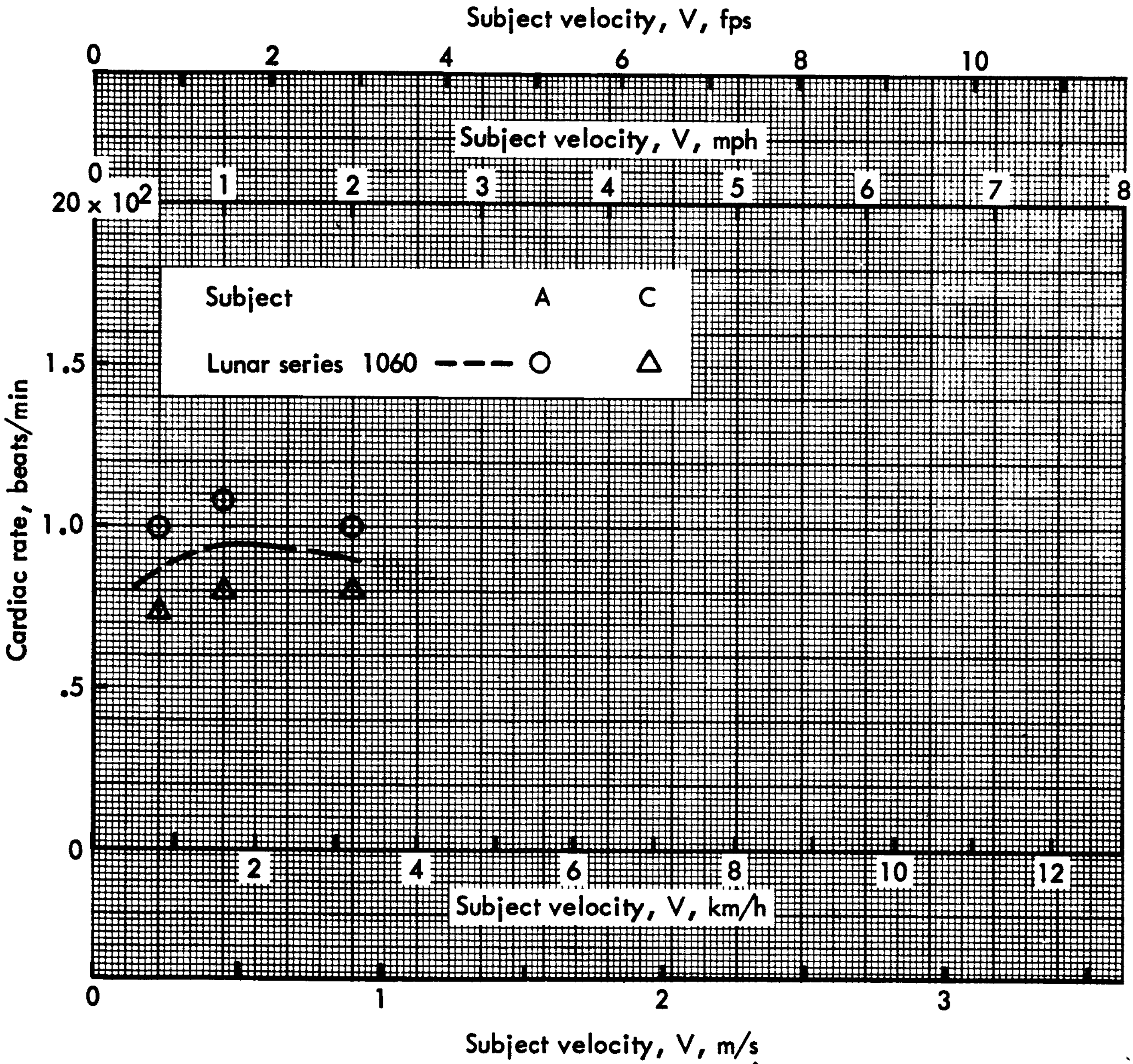


Figure 172. – Average cardiac rate versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

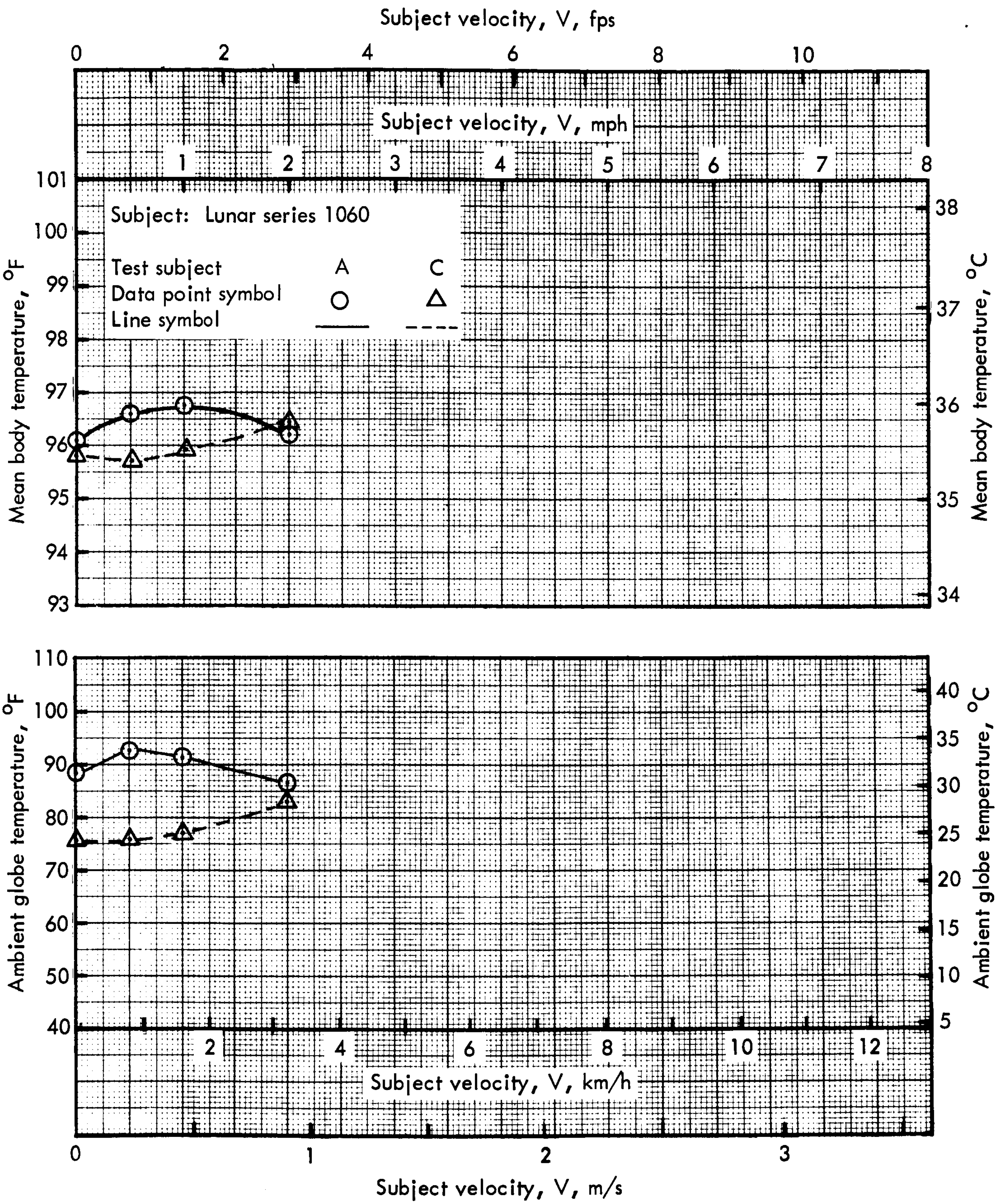


Figure 173. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity descending at 20 degrees walking.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 1120

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	jumping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	17	7	5

Respiration,	respiratory rate	Figure 174
	respiratory volume expired	Figure 175 *
Metabolism,	metabolic energy expenditure rate	Figure 176
	metabolic energy expenditure rate per unit length	Figure 177
	oxygen consumption	Figure 178
	oxygen consumption per unit length	Figure 179
Cardiovascular function,	cardiac rate	Figure 180
Body temperature,	mean body temperature	Figure 181
Pressure suit environmental data		Not obtained

Comments:

*Only Subjects A and B performed tests at 3.0 and 4.0 mph

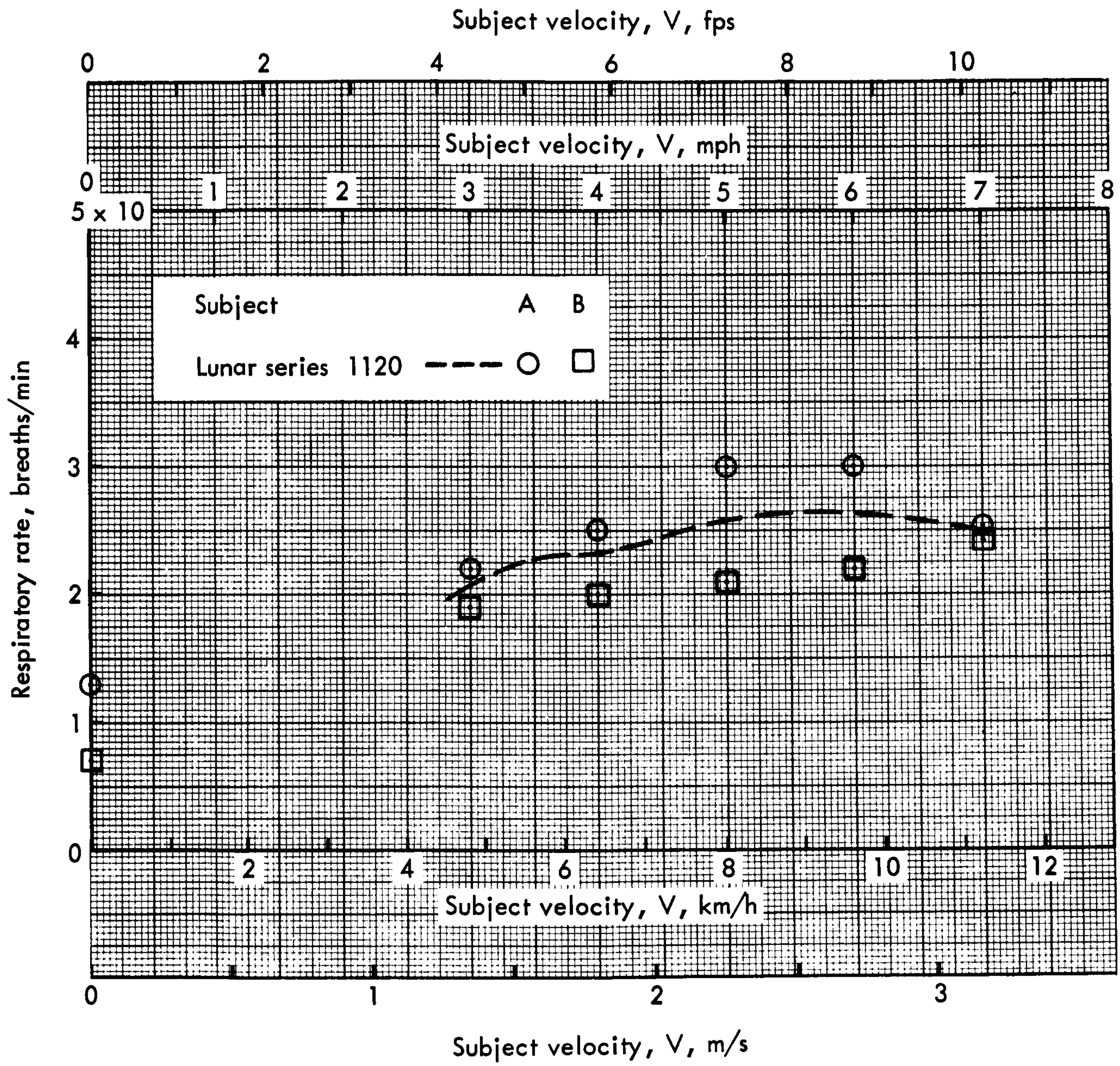


Figure 174. – Average respiratory rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

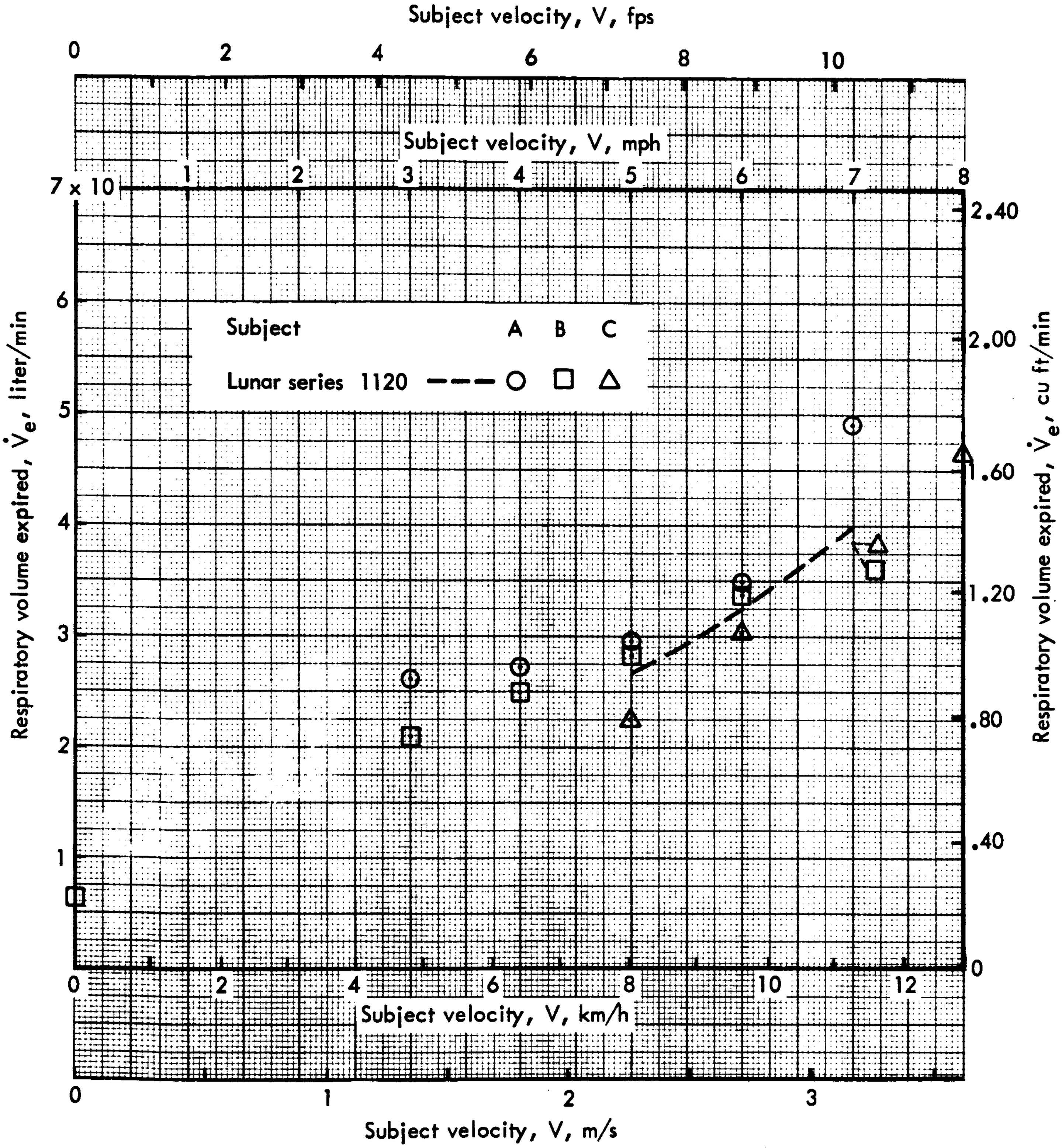


Figure 175. – Average mean respiratory volume versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

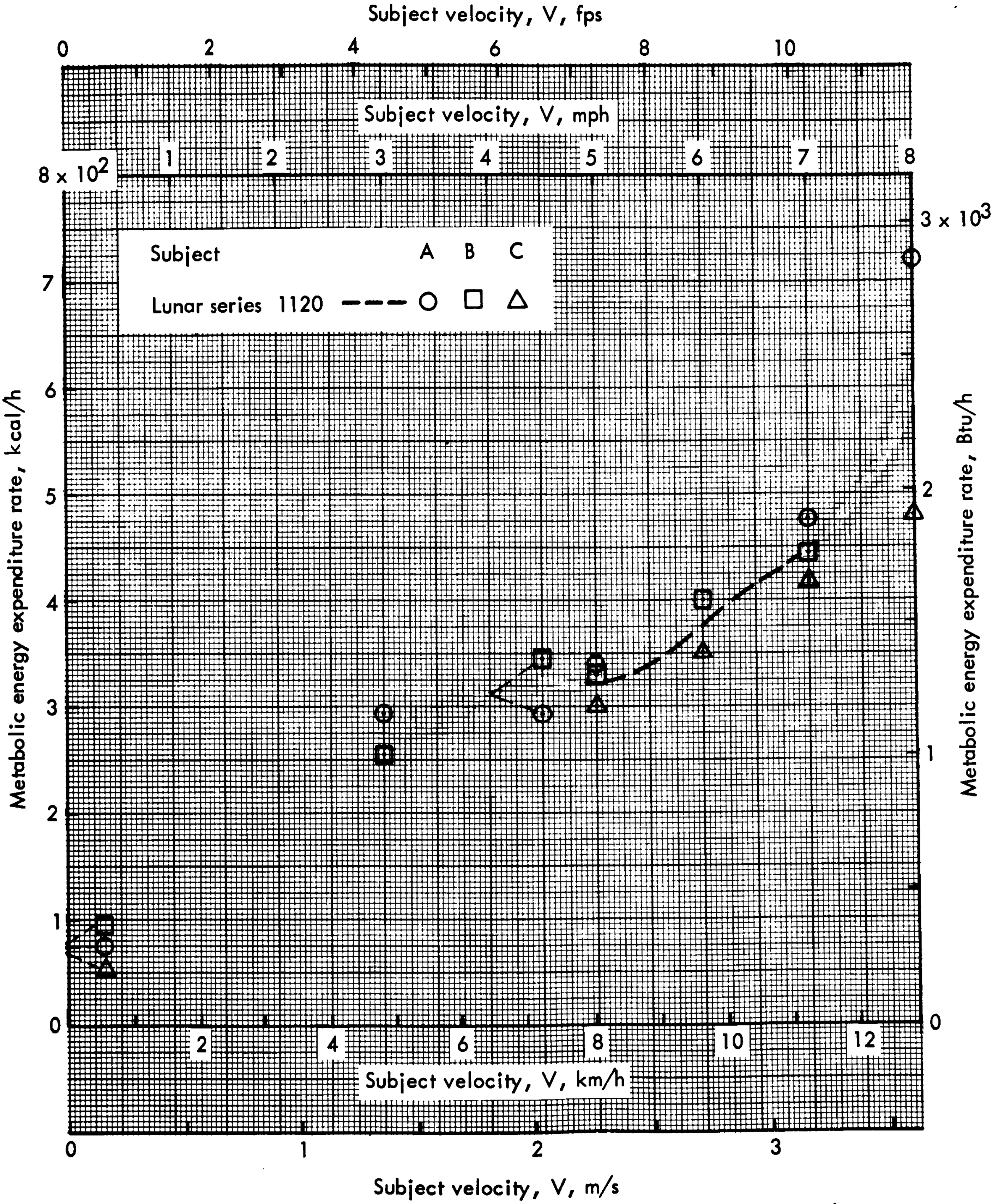


Figure 176. – Average metabolic energy expenditure rate versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

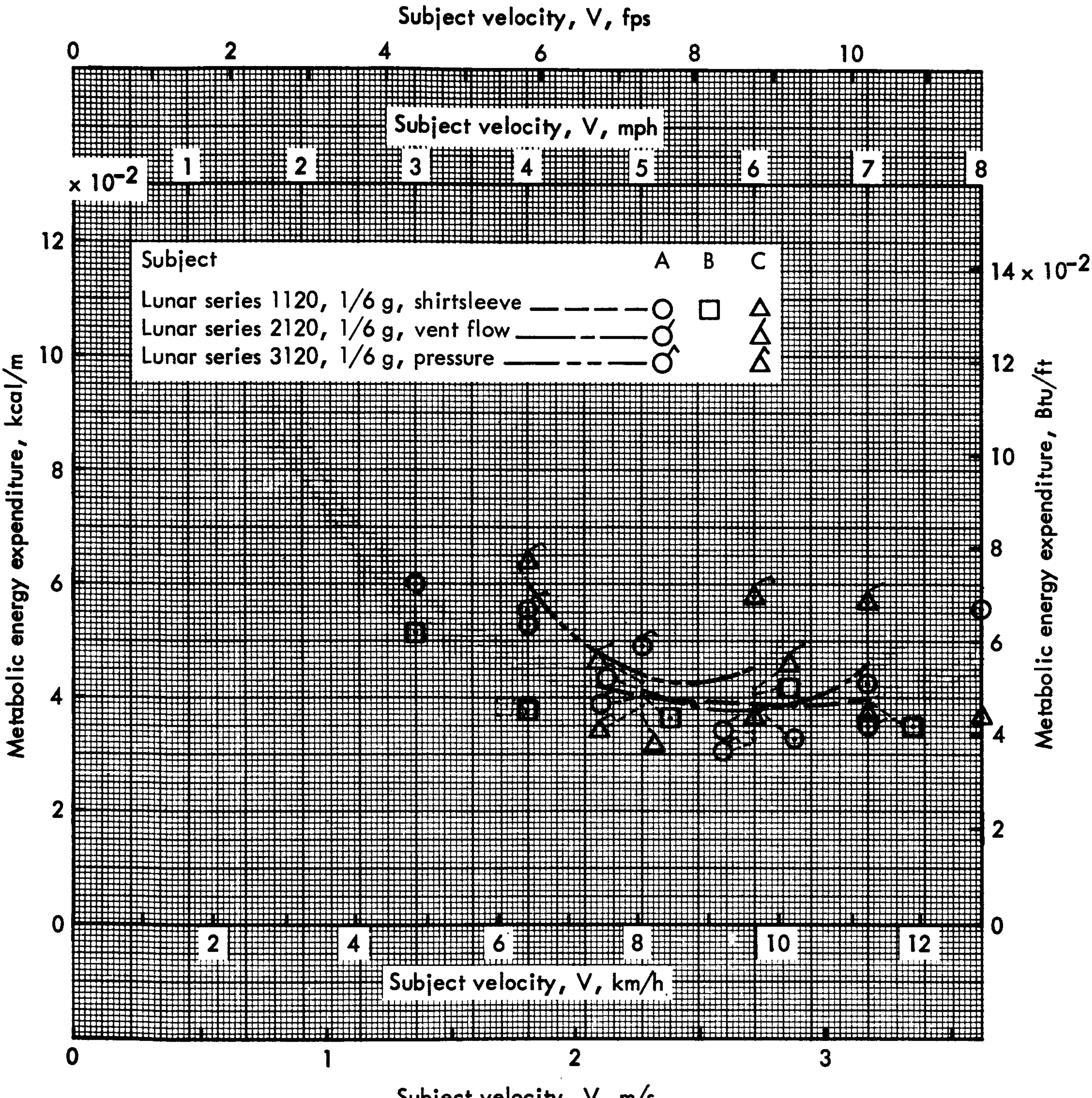


Figure 177. – Average metabolic energy expenditure per unit length versus subject velocity jumping horizontally.

Comparison of 1/6 g, test conditions between shirtsleeve vent flow and pressure

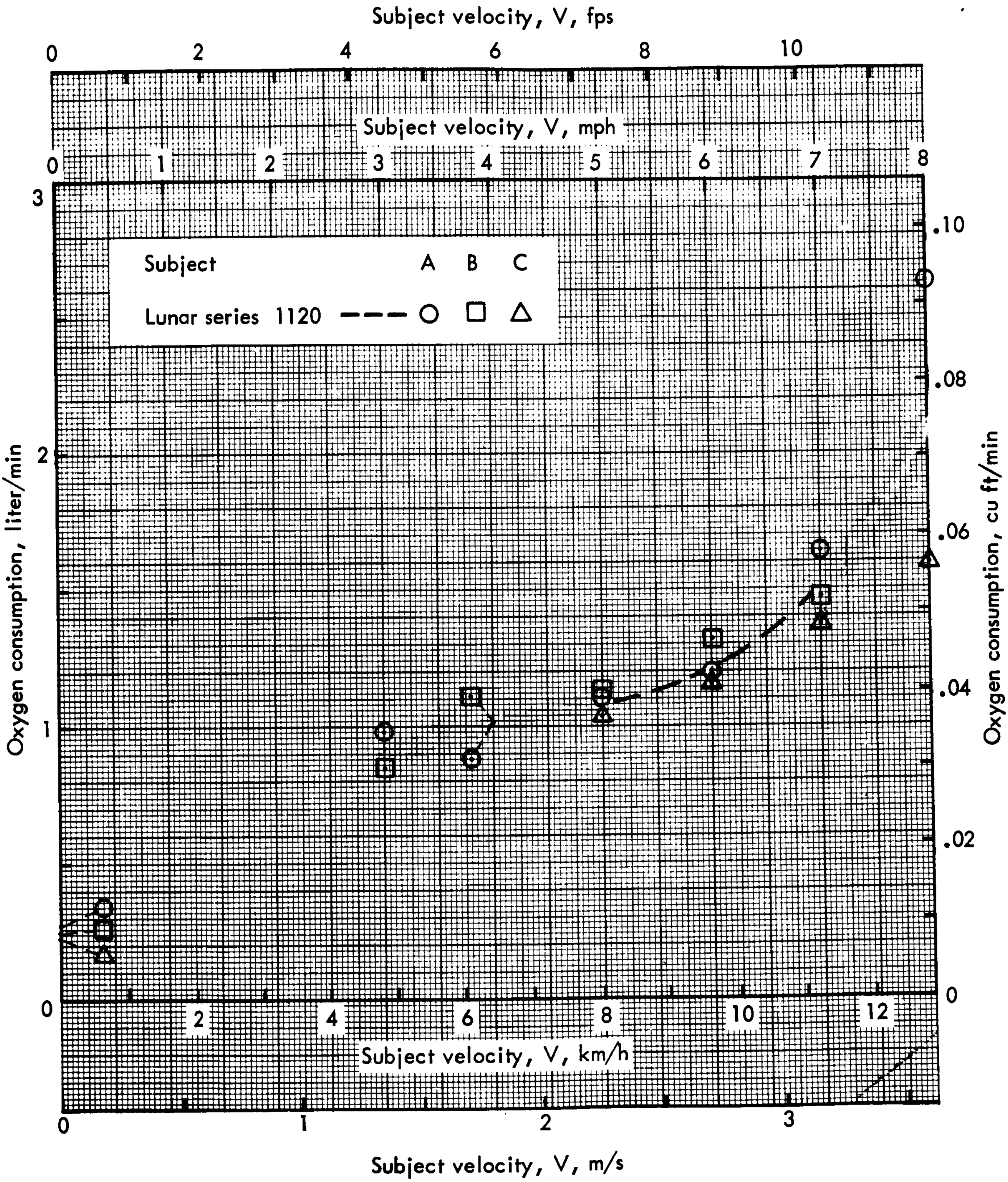


Figure 178. – Average oxygen consumption versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

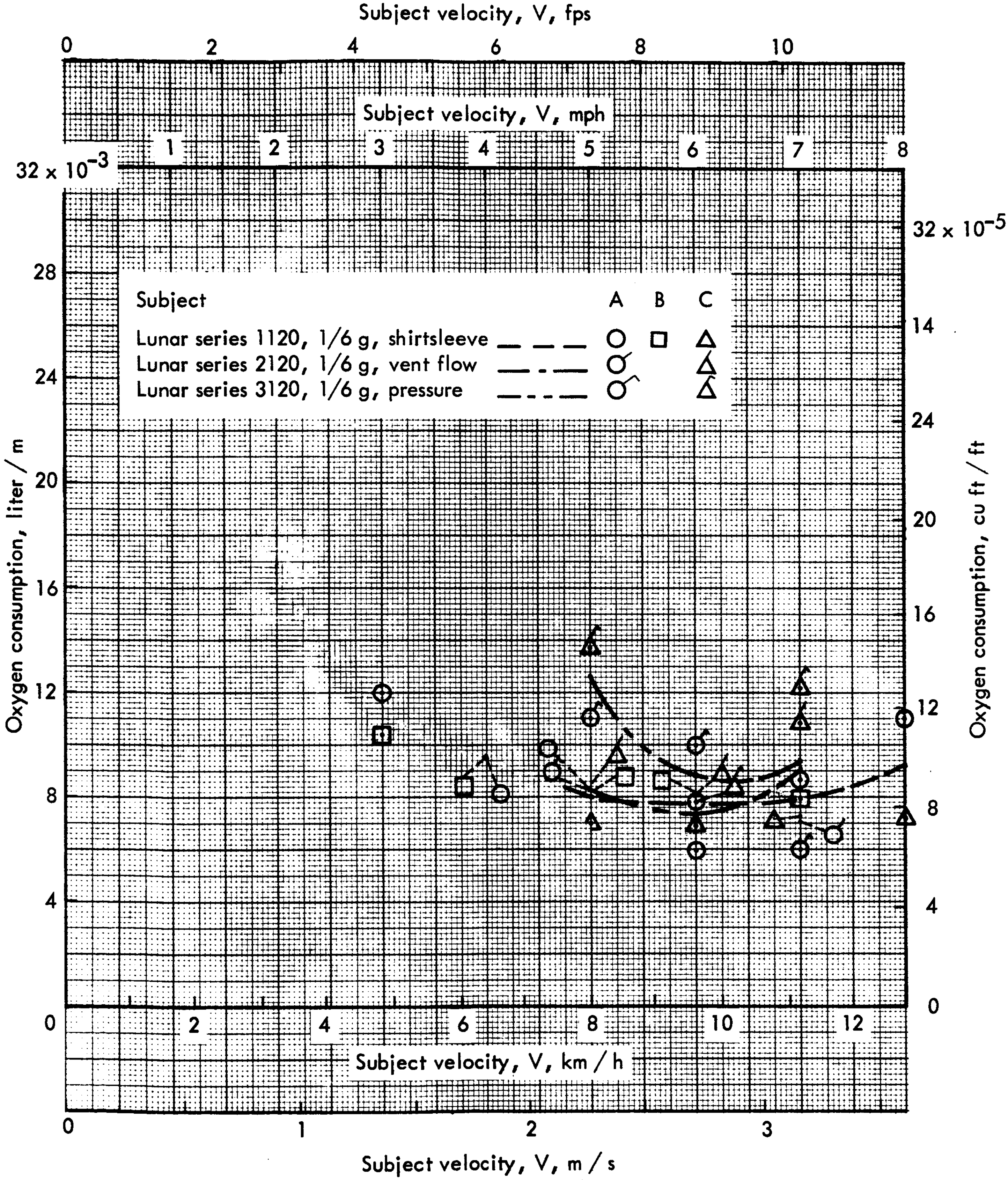


Figure 179. – Average oxygen consumption per unit length versus subject velocity jumping horizontally.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

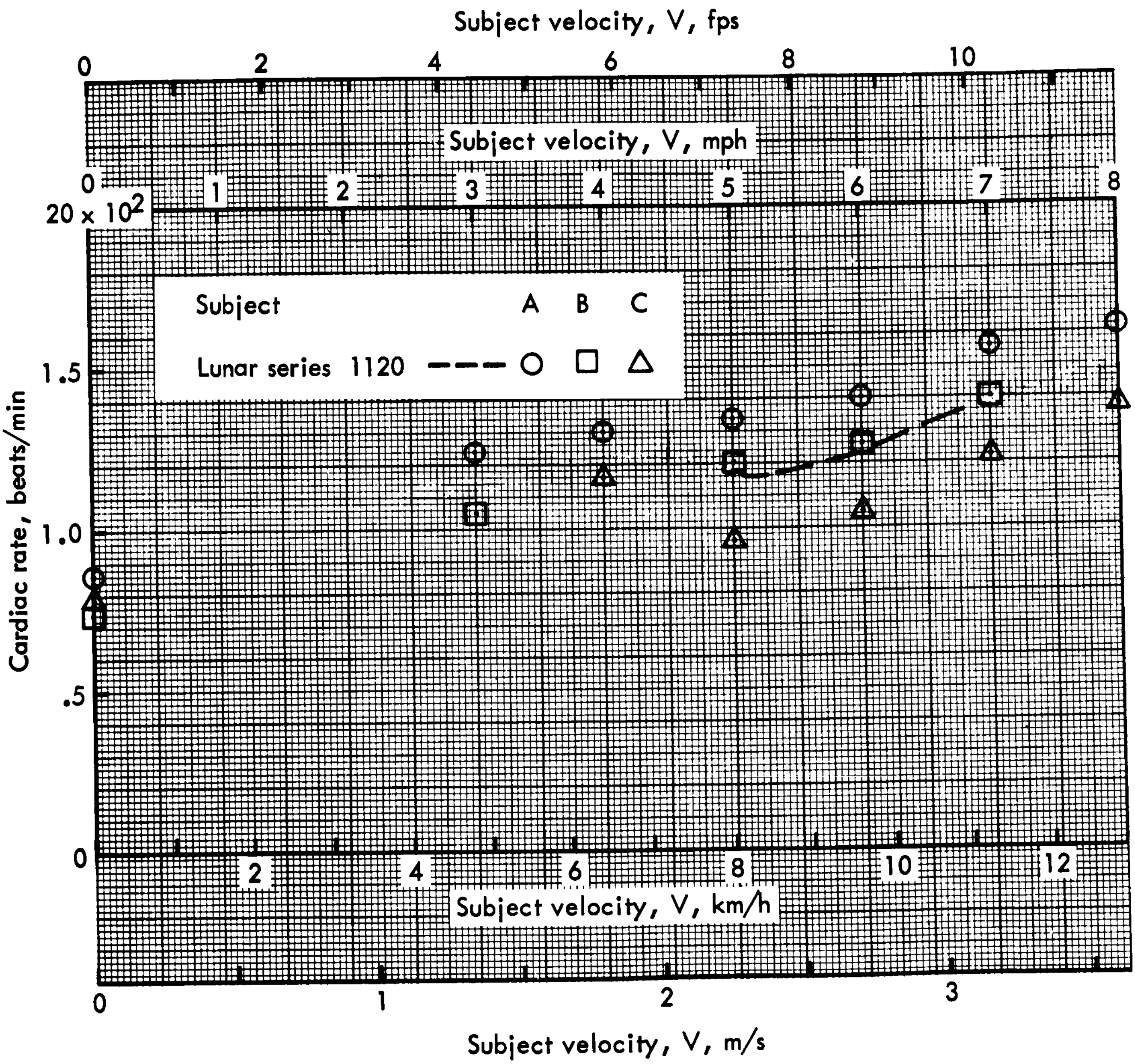


Figure 180. – Average cardiac rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, shirtsleeve, susp. gear pack I

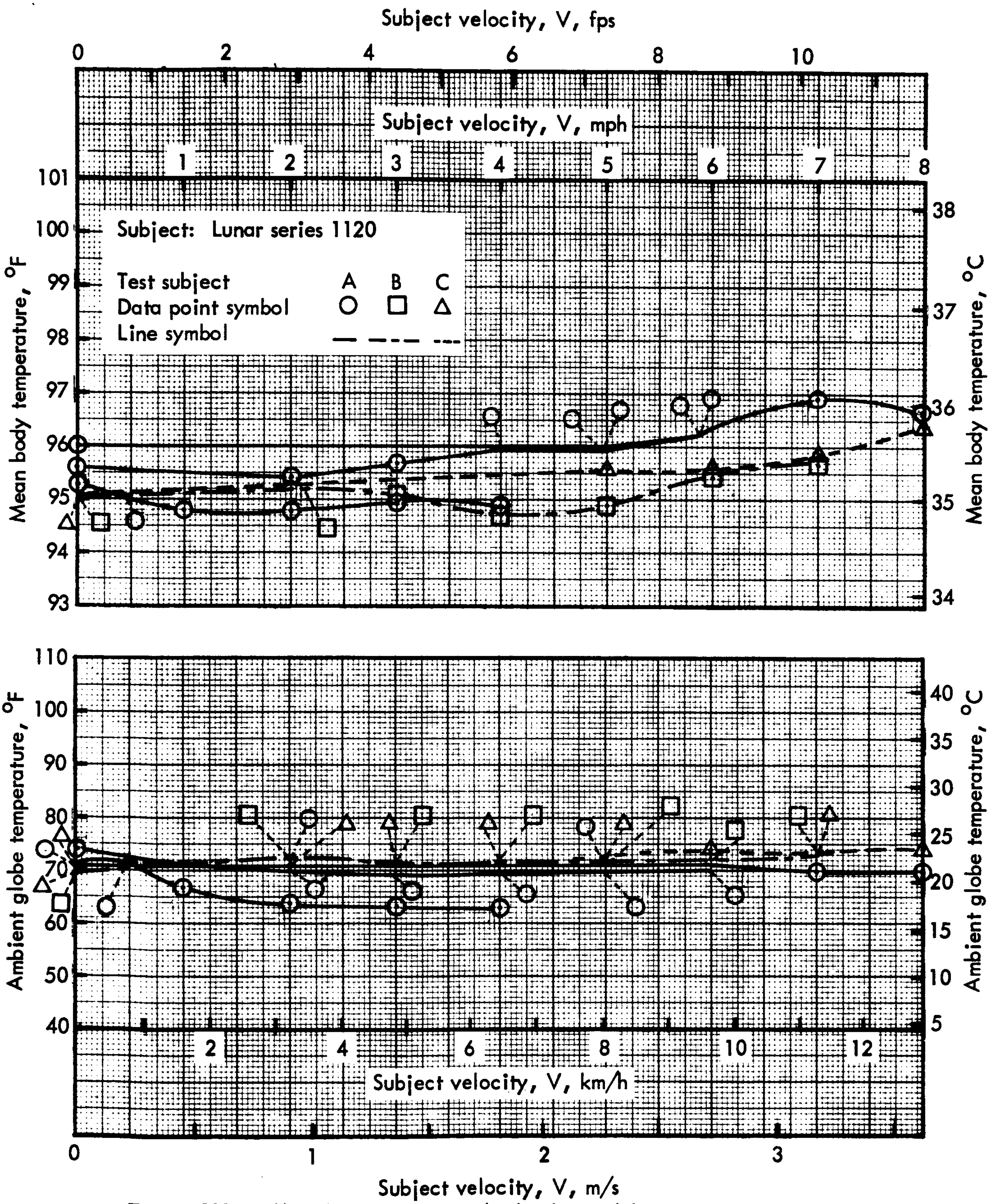


Figure 181. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2120

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	jumping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	4		4

Respiration,	respiratory rate	Figure 182*
	respiratory volume expired	Figure 183
Metabolism,	metabolic energy expenditure rate	Figure 184
	metabolic energy expenditure rate per unit length	Figure 177
	oxygen consumption	Figure 185
	oxygen consumption per unit length	Figure 179
Cardiovascular function, cardiac rate		Figure 186
Body temperature, mean body temperature		Figure 187
Pressure suit environmental data		Figure 188

Comments:

*Respiratory rate for subject A was not obtained.

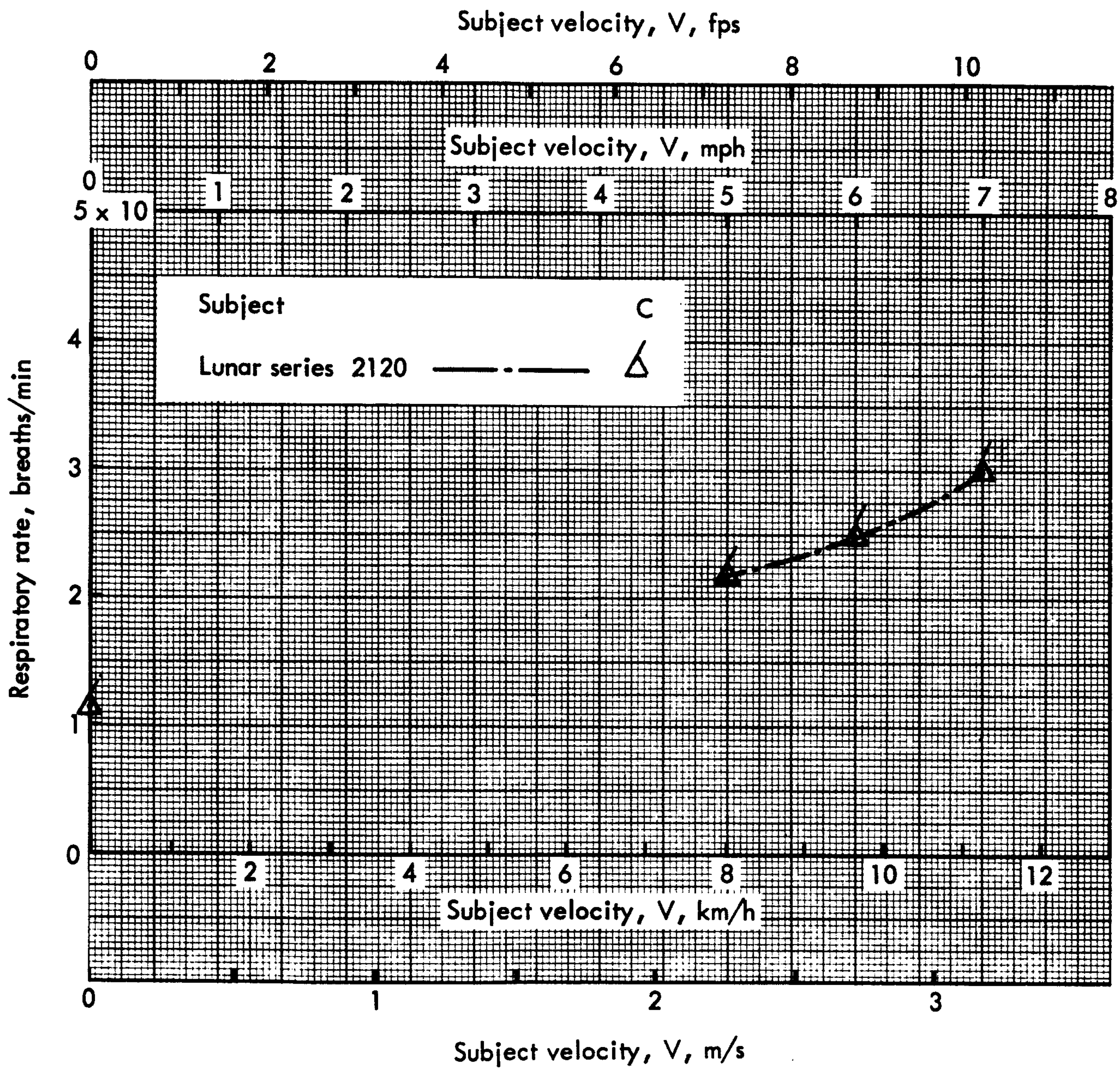


Figure 182. – Respiratory rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

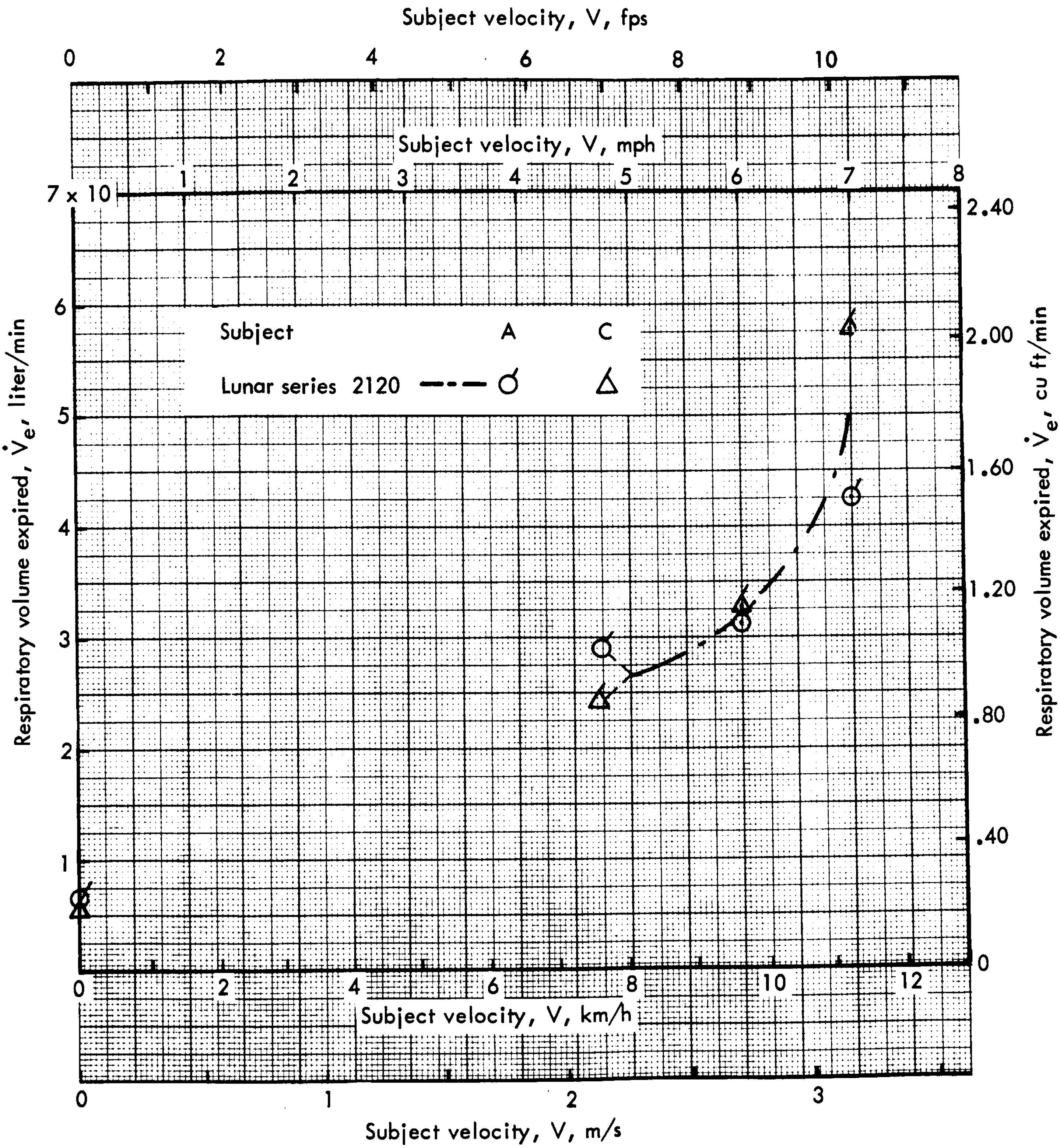


Figure 183. – Average mean respiratory volume versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

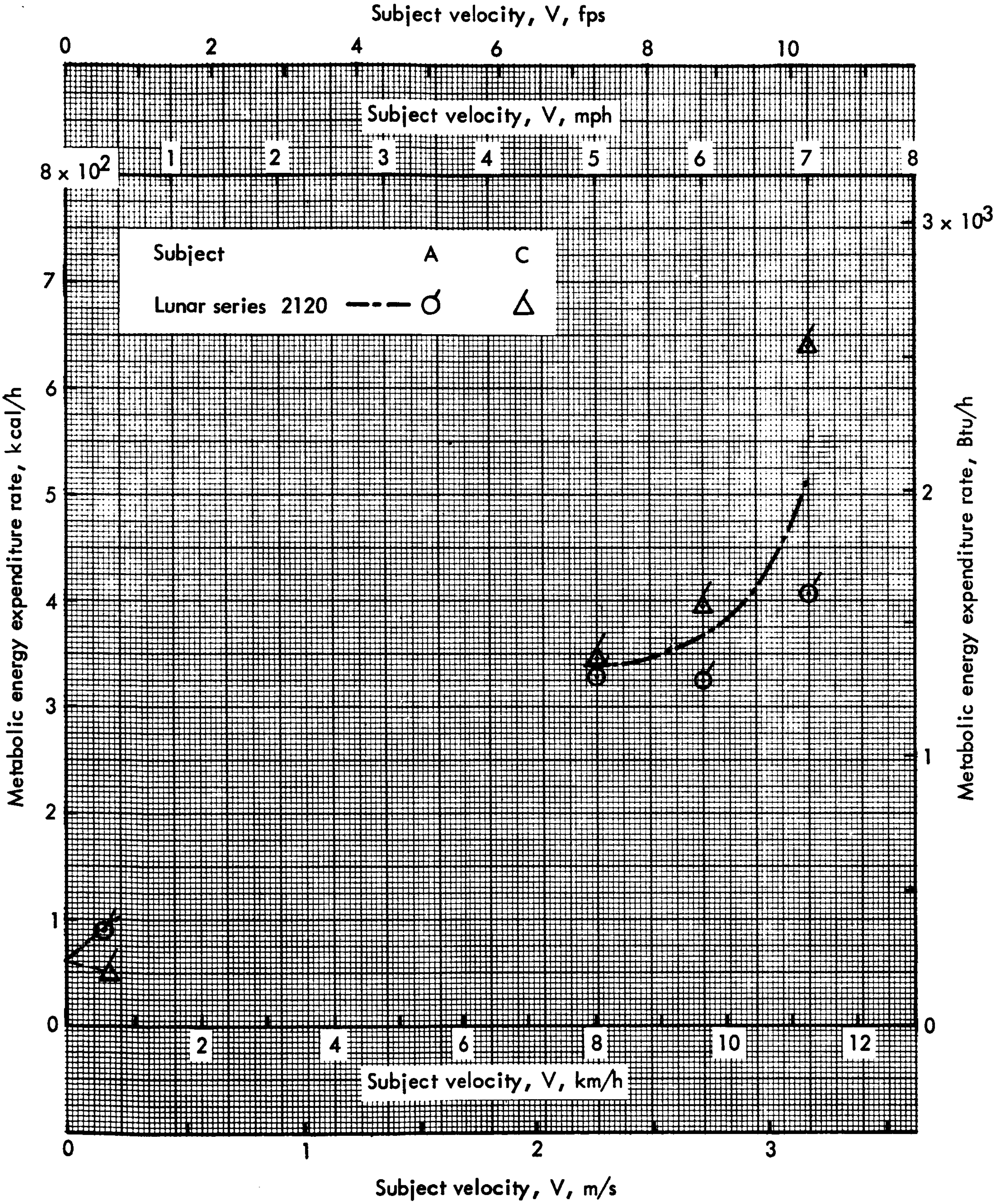


Figure 184. – Average metabolic energy expenditure rate versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

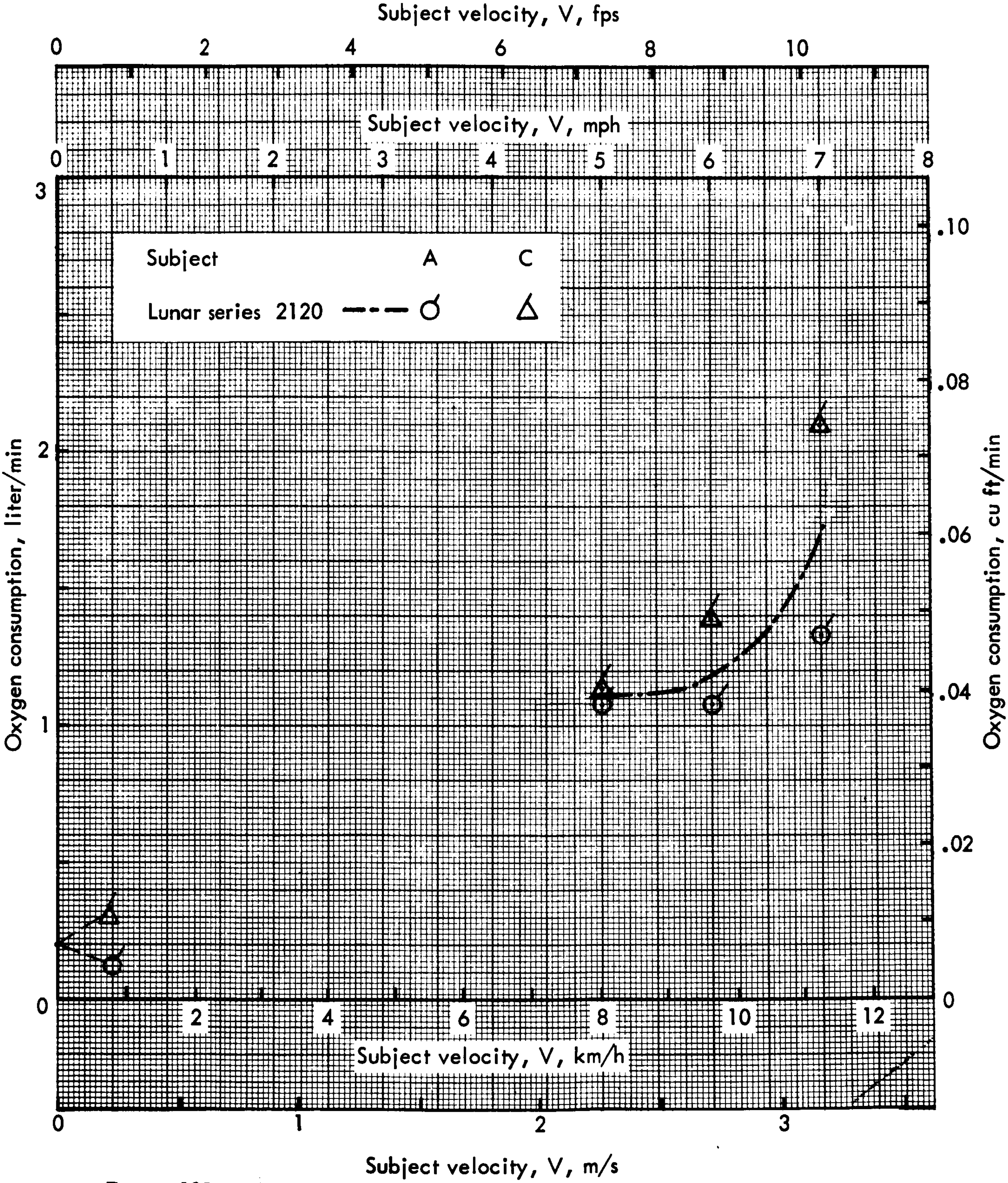


Figure 185. – Average oxygen consumption versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

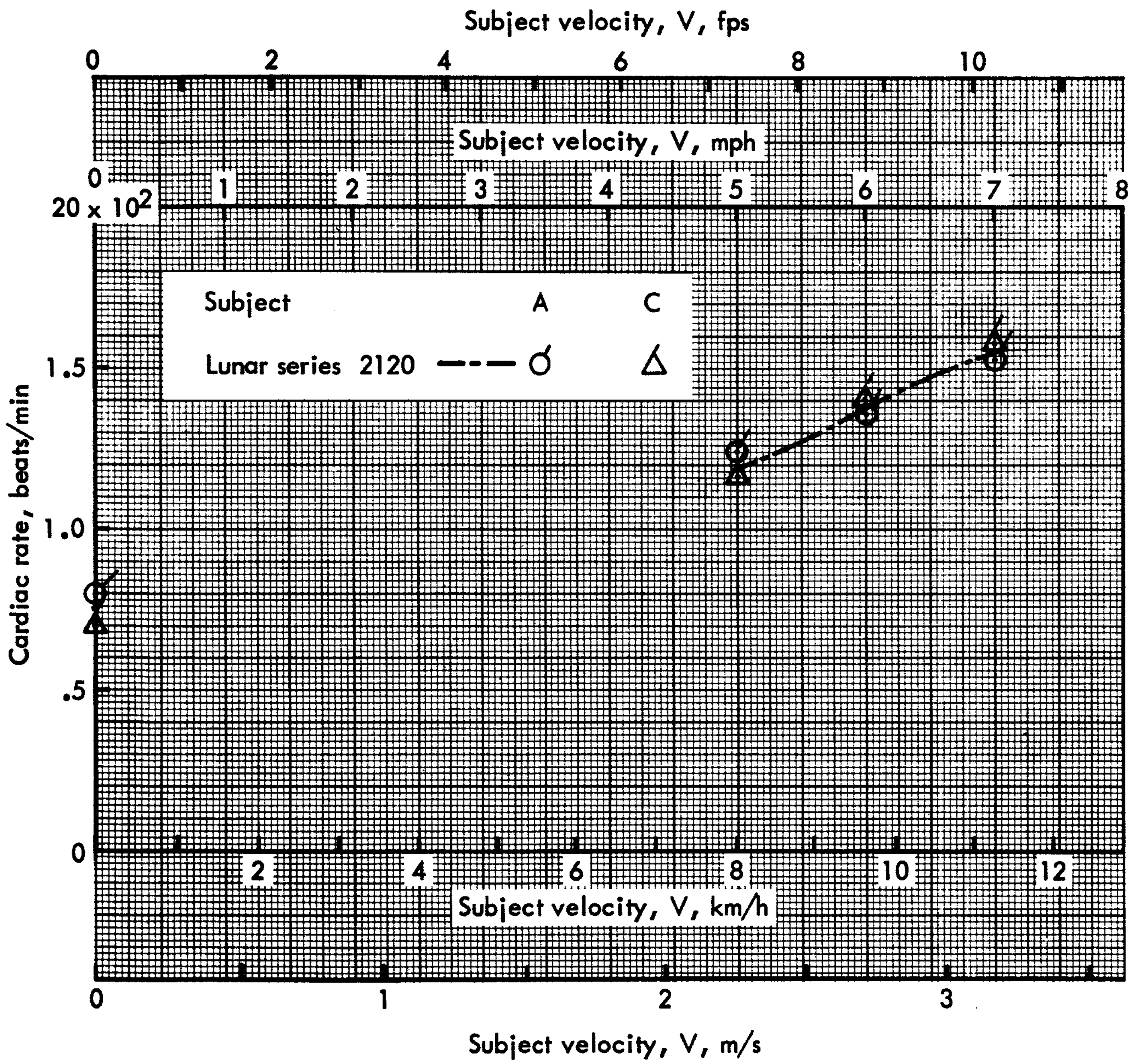


Figure 186. – Average cardiac rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

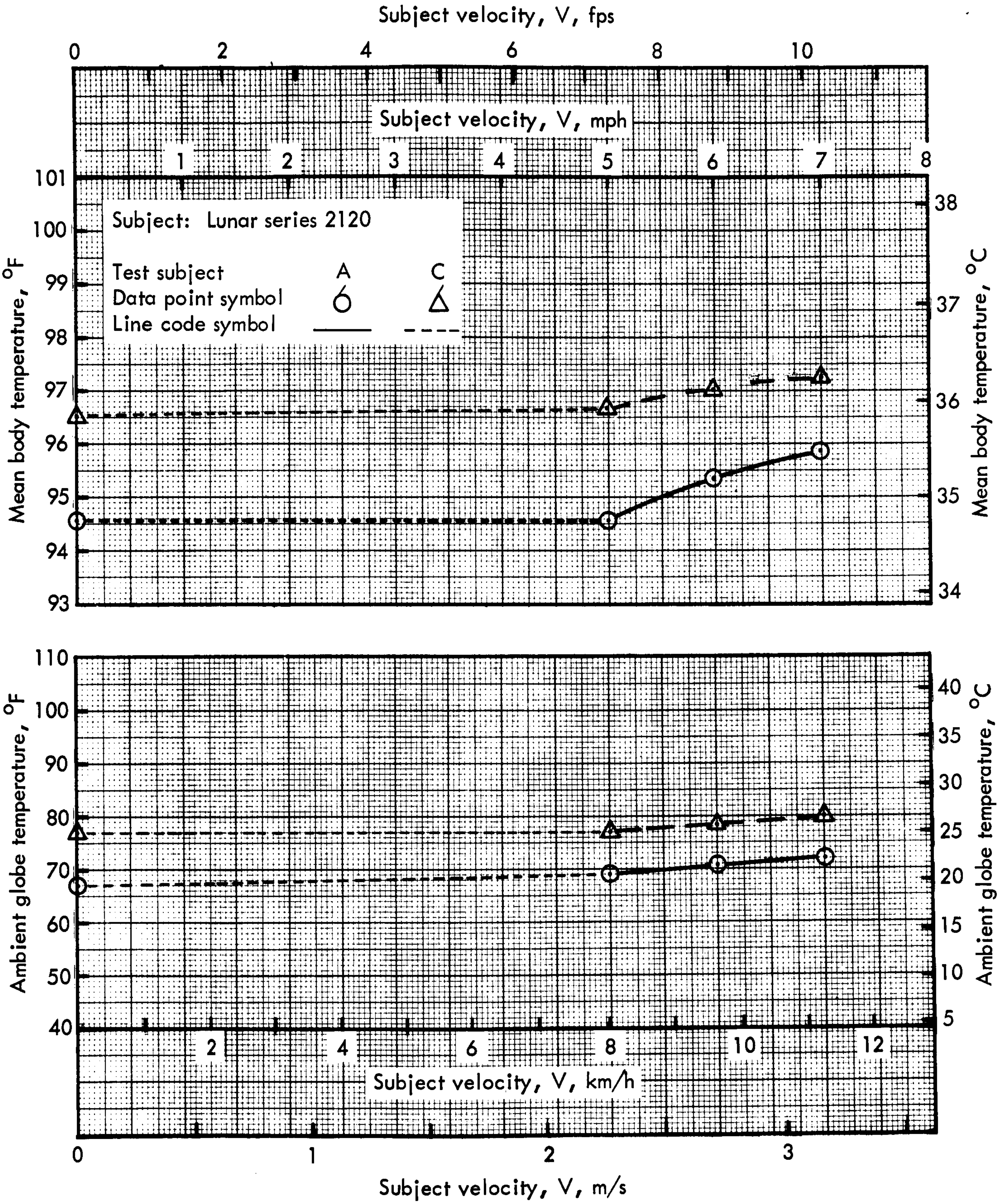


Figure 187. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

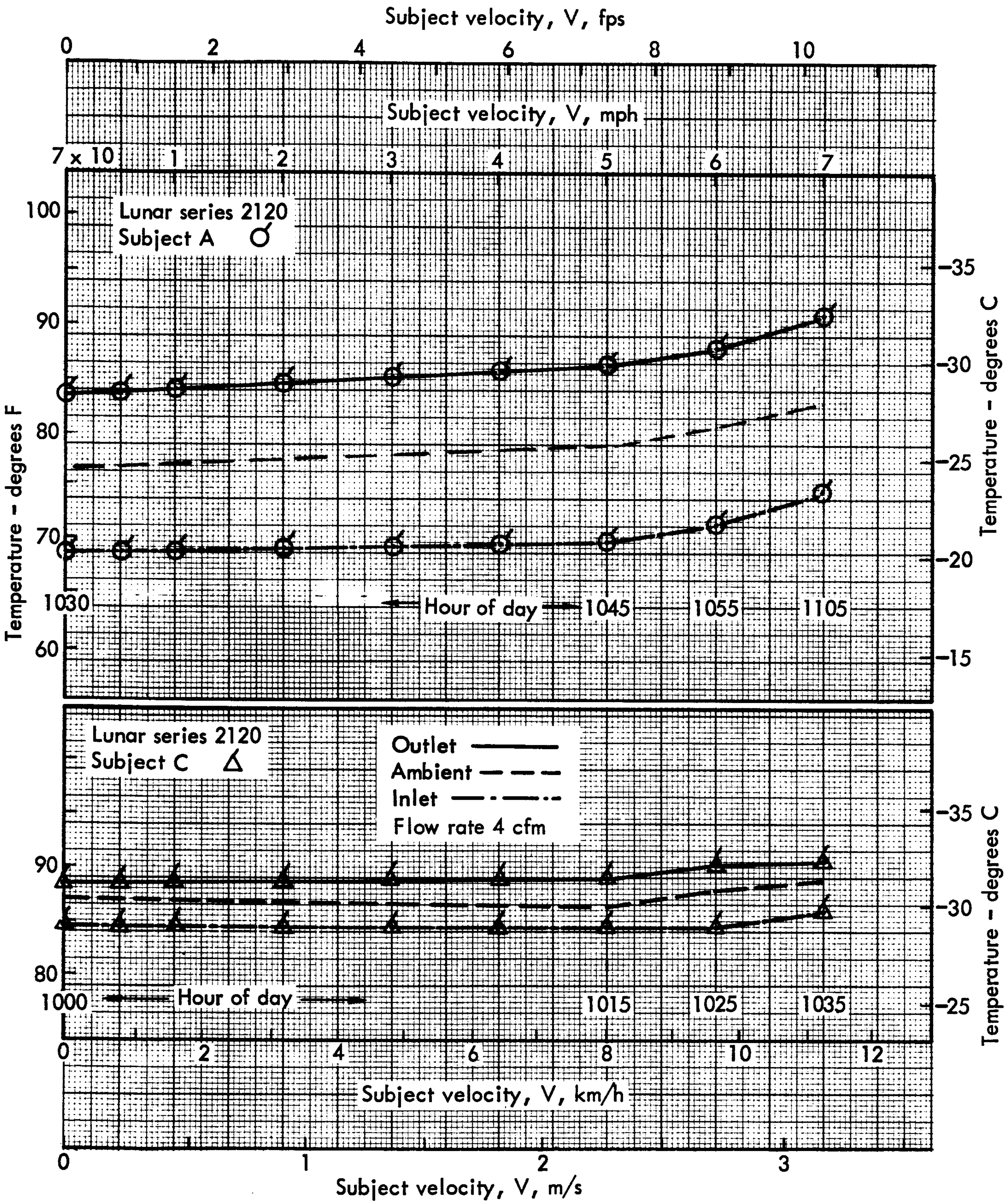


Figure 188. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity jumping horizontally. Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3120

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	jumping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	4		4

Respiration, respiratory rate	Figure 189*
respiratory volume expired	Figure 190
Metabolism, metabolic energy expenditure rate	Figure 191
metabolic energy expenditure rate per unit length	Figure 177
oxygen consumption	Figure 192
oxygen consumption per unit length	Figure 179
Cardiovascular function, cardiac rate	Figure 193
Body temperature, mean body temperature	Figure 194
Pressure suit environmental data	Figure 195

Comments:

*Only the respiratory rate for subject C standing at rest was obtained.

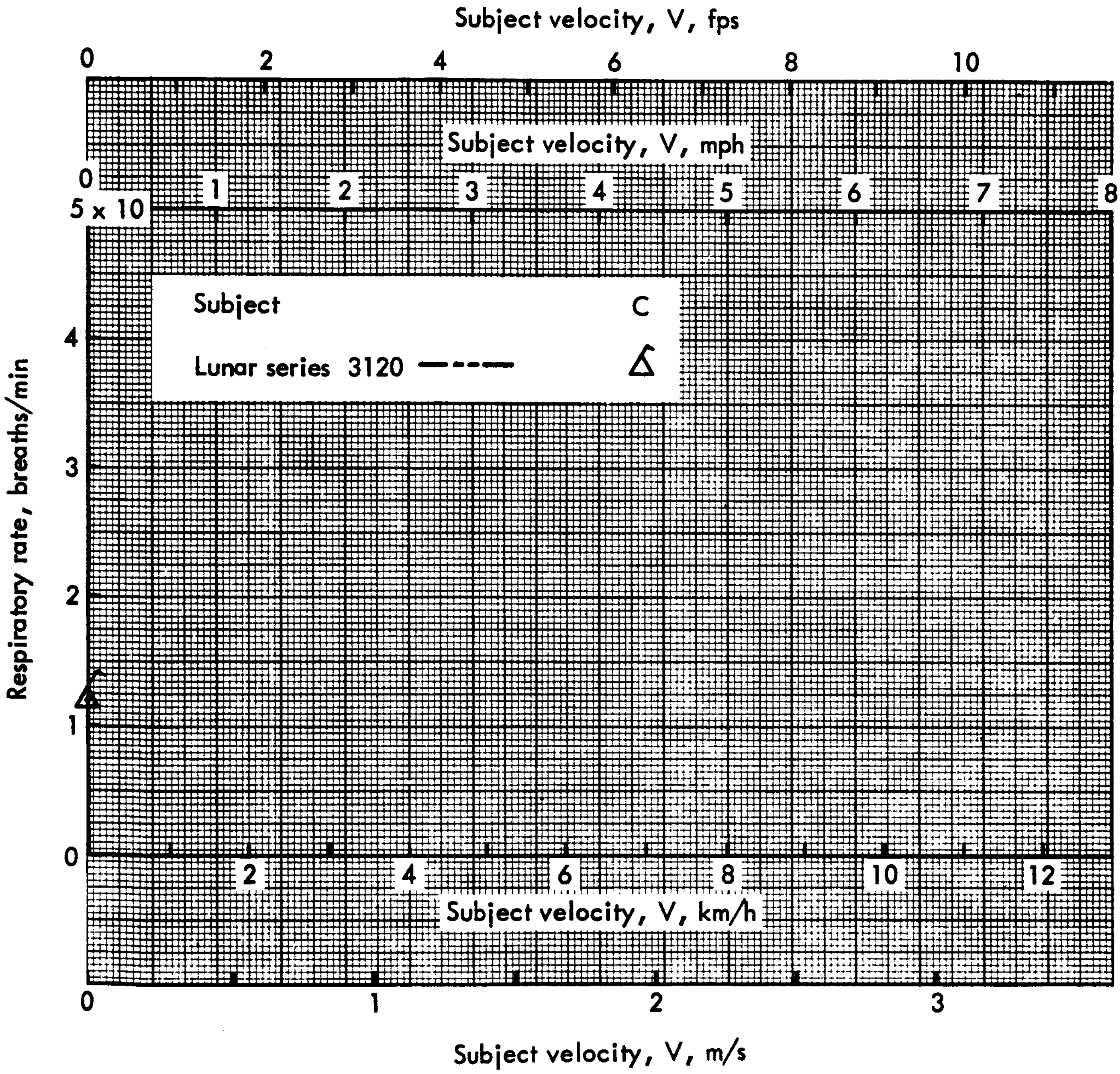


Figure 189. – Average respiratory rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

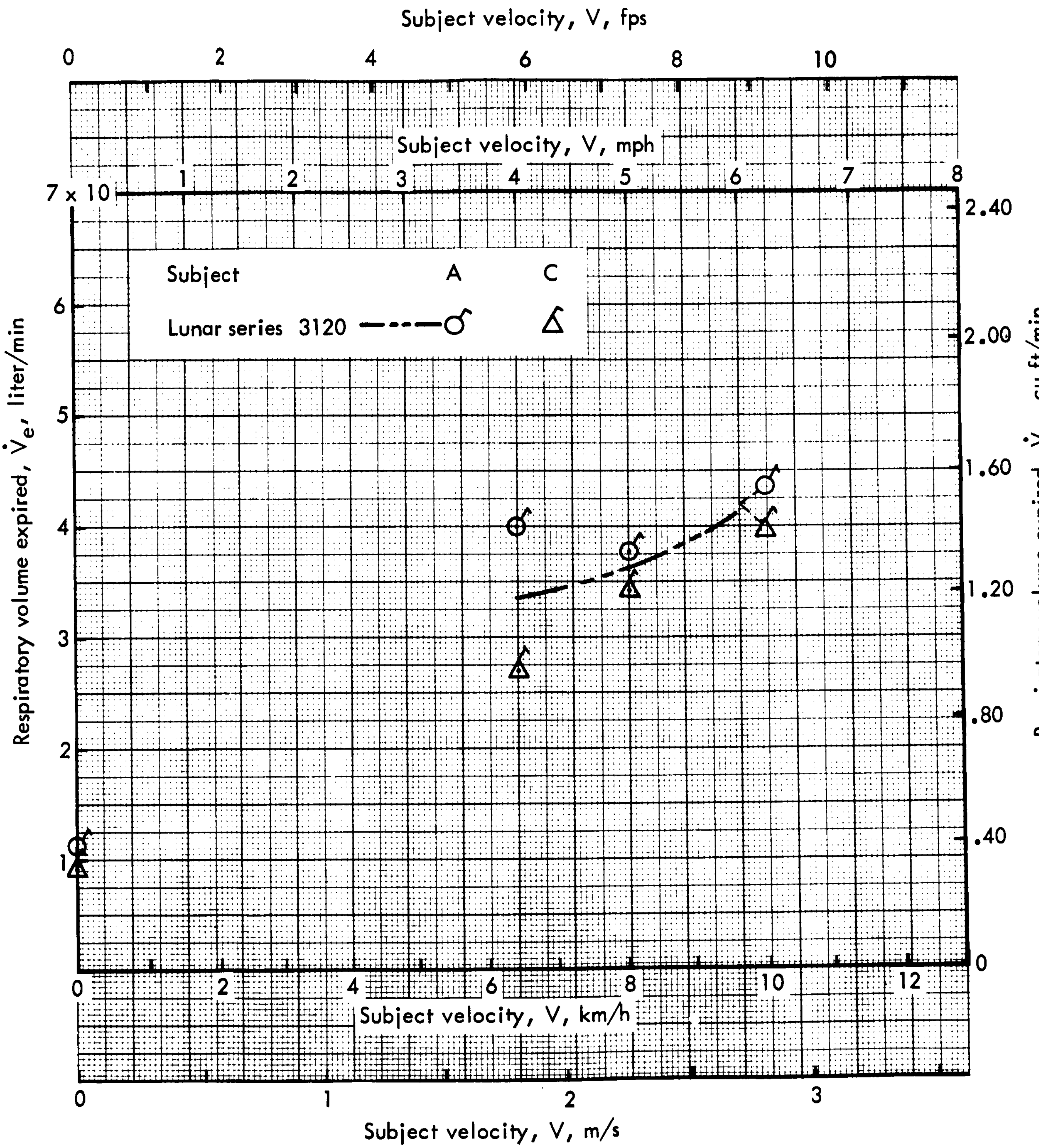


Figure 190. – Average mean respiratory volume versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

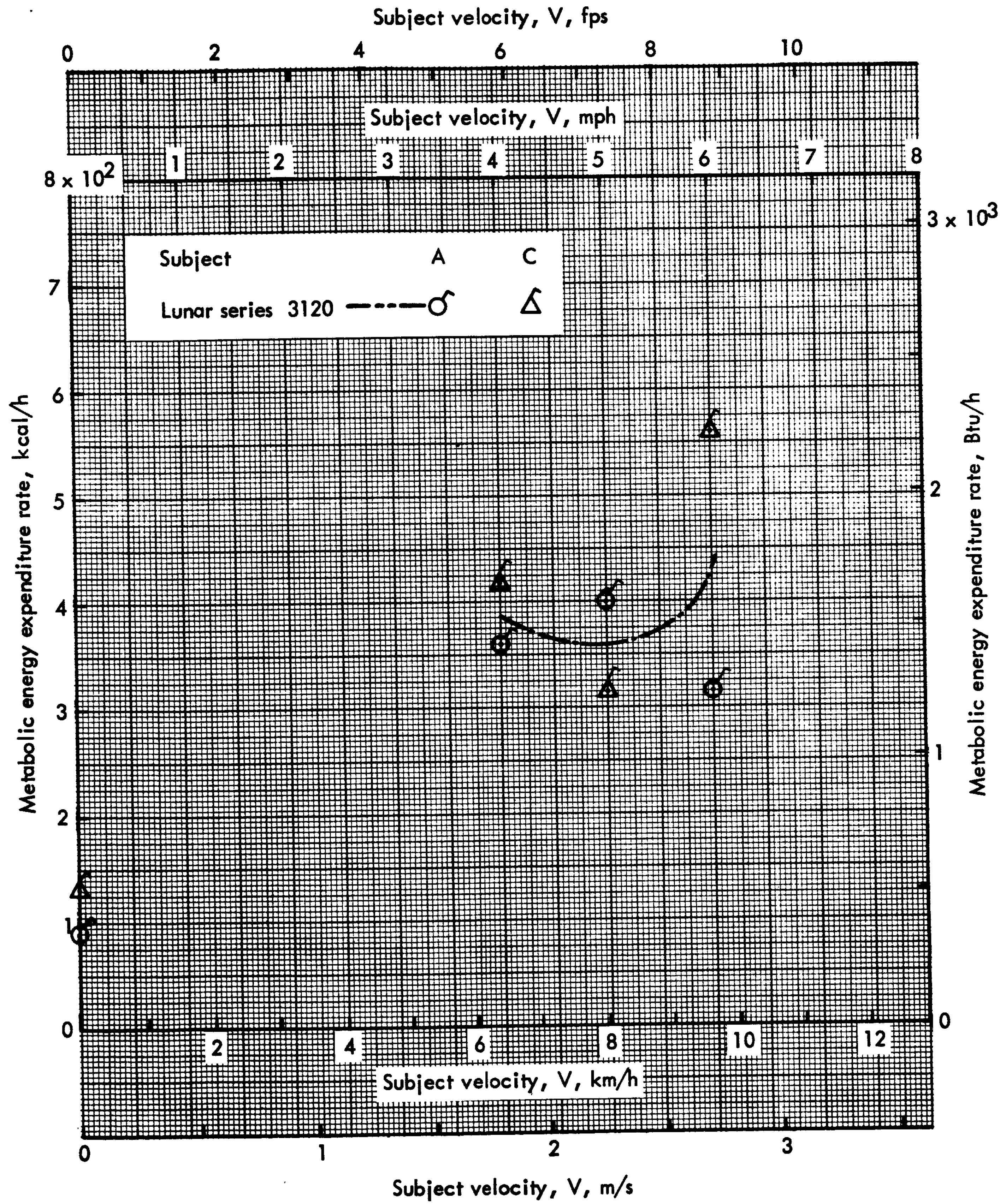


Figure 191. – Average metabolic energy expenditure rate versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

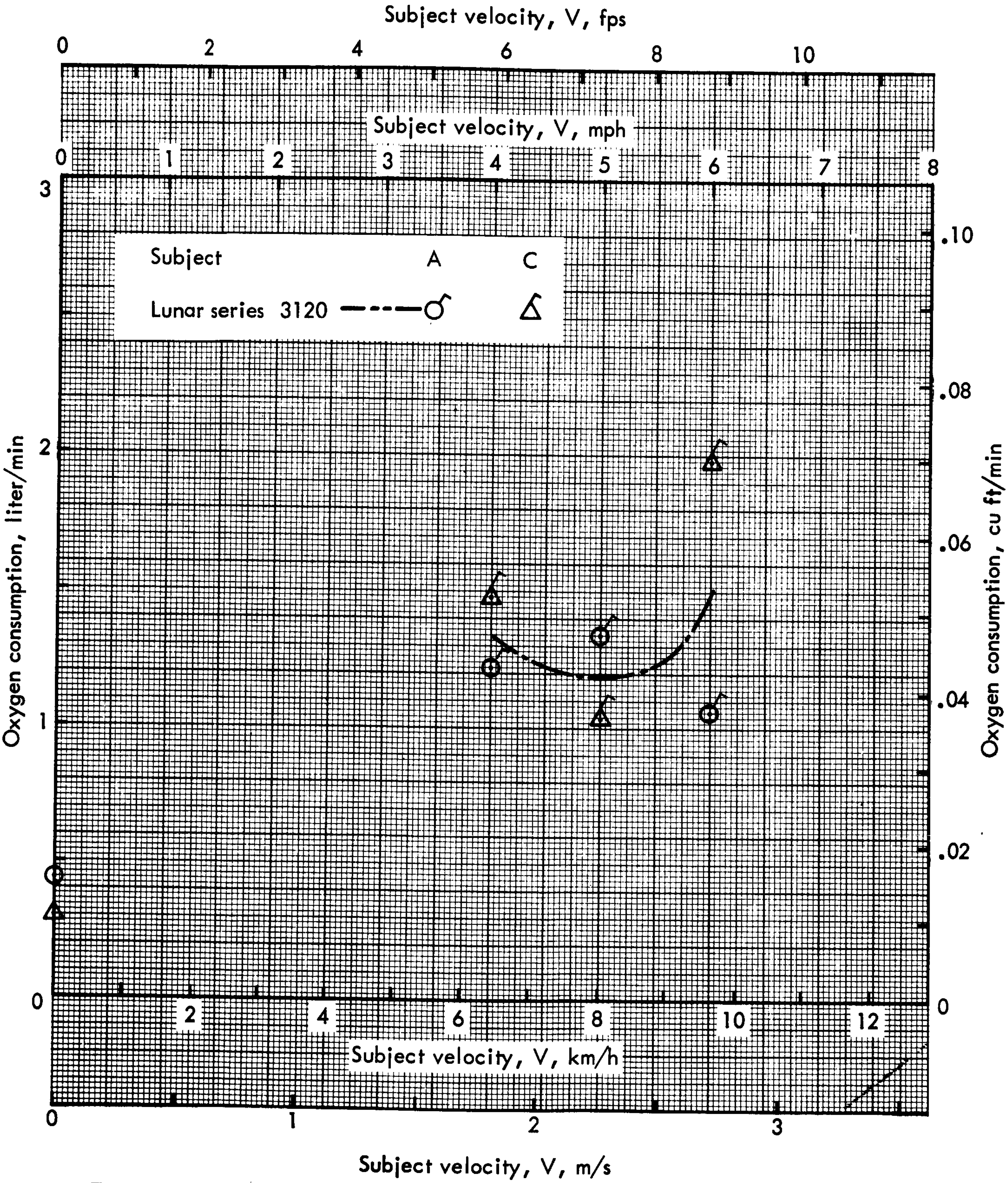


Figure 192. – Average oxygen consumption versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

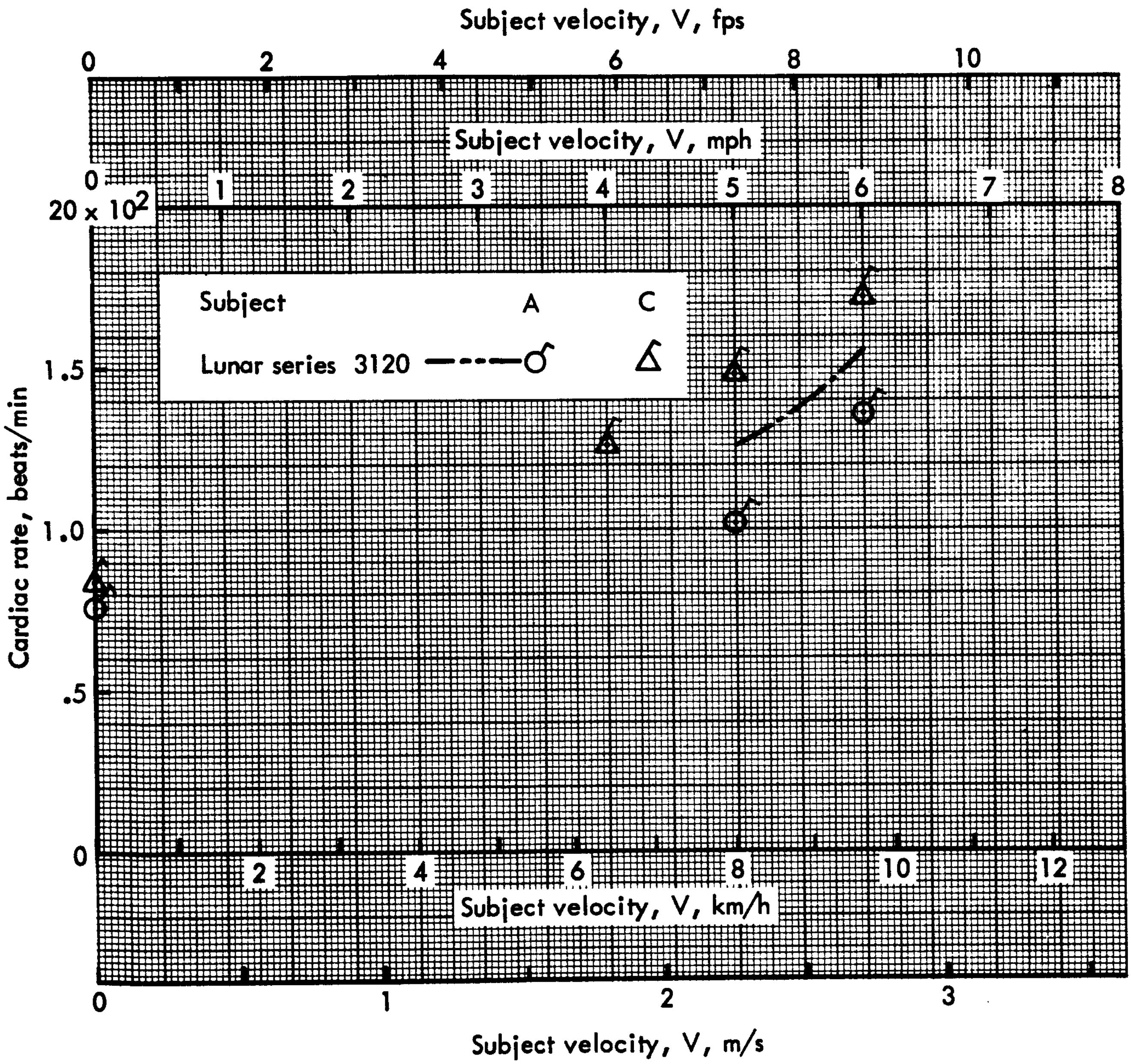


Figure 193. – Average cardiac rate versus subject velocity jumping horizontally.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

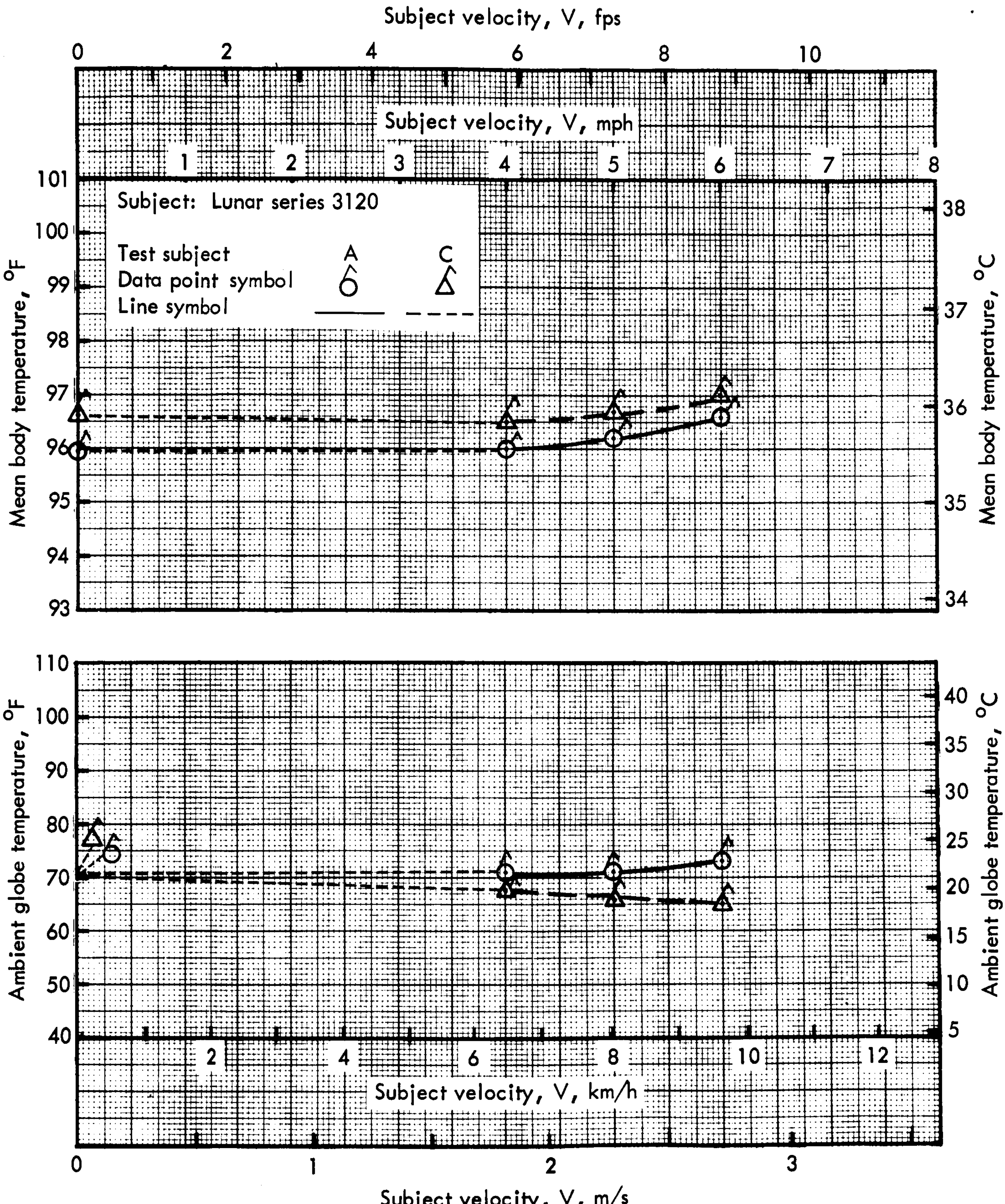


Figure 194. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

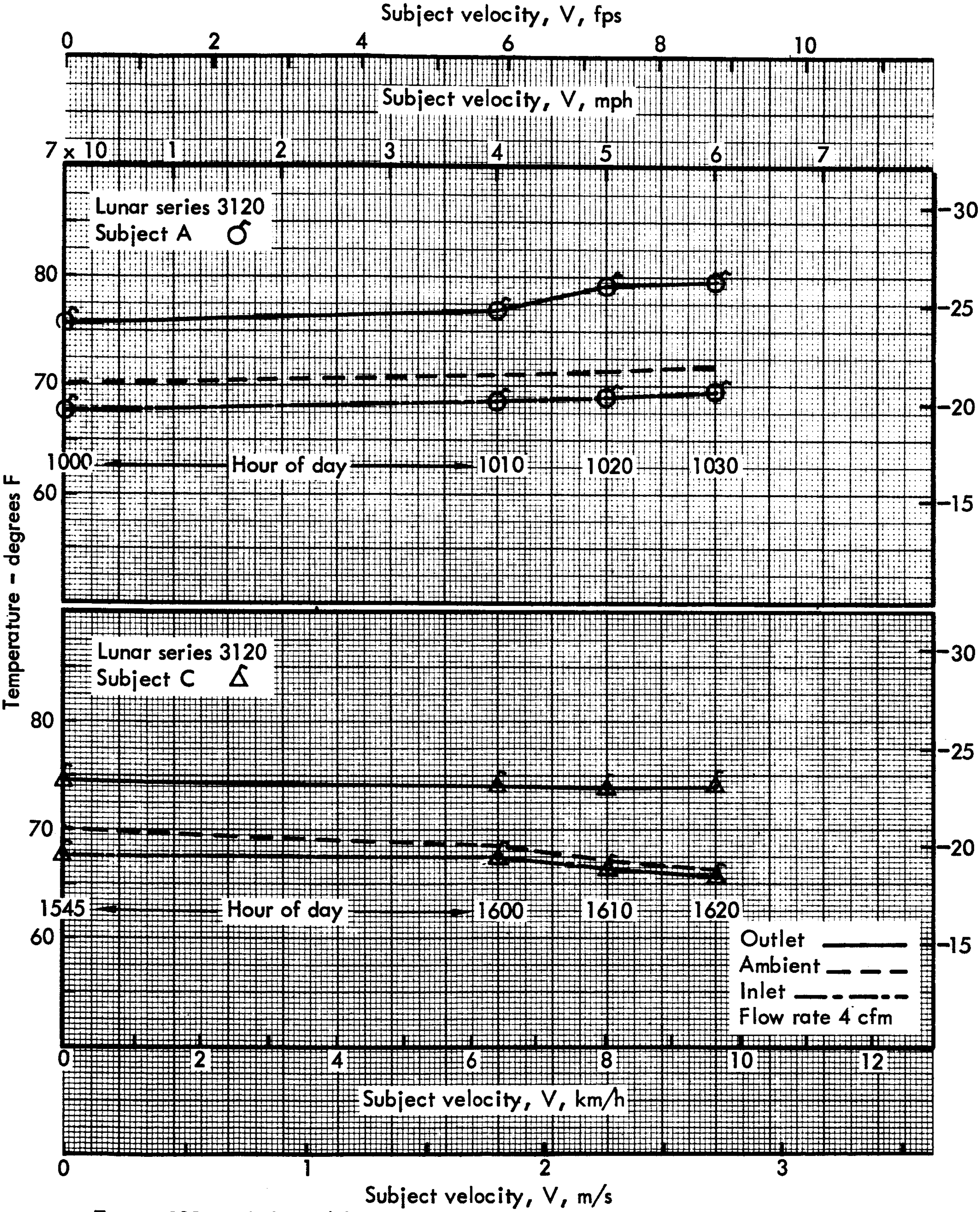


Figure 195. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity jumping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series 1180

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	stair stepping	Work Variable	ascend. & descend. at 35°
Gravity: Lunar	x	Earth	

Test Location: *

1/6 g Treadmill		One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x	x	x
Number of Tests	5	5	5

Respiration, respiratory rate	Figure 197
respiratory volume expired	Figure 198
Metabolism, metabolic energy expenditure rate	Figure 199
metabolic energy expenditure rate per unit length	Figure 200
oxygen consumption	Figure 201
oxygen consumption per unit length	Figure 202
Cardiovascular function, cardiac rate	Figure 203
Body temperature, mean body temperature	Figure 204
Pressure suit environmental data	Not obtained

Comments:

The arrangement for the tests conducted in this series is shown in Figure 196 .

* See discussion on following page.

Stair Stepping. - Since the biomechanical studies included stair stepping, it was desirable to include this type of activity in the physiological tests. The stairs used are described fully in Volume I, Part 2. There were 18 steps, each having seven inch rise with ten inch tread. The resulting flight of stairs made an angle of 35° with the simulated "horizontal" of the LGS.

The inherent constraint of the LGS support system made it necessary, in the physiological study, for the subject to climb upward facing forward, and then in effect to back down the stairs. This process was repeated at various stepping rates, for seven or eight minutes at each velocity in the shirt sleeve condition, for four to seven minutes in the ventilated pressure suit condition, and for three minutes in the pressurized suit condition. Comparable tests at one g were not performed.

The distance covered by the subject, as used in the computations, was measured along the angle of the stairs. The velocity of progression was calculated from the total distance (up and down) accumulated in the time period of each test. Actual velocities achieved were in the range from .25 to 1.89 mph (.5 to 3 km/h). Figure 196 shows a subject on the stairs, in shirt sleeve suit, carrying instrument pack I.

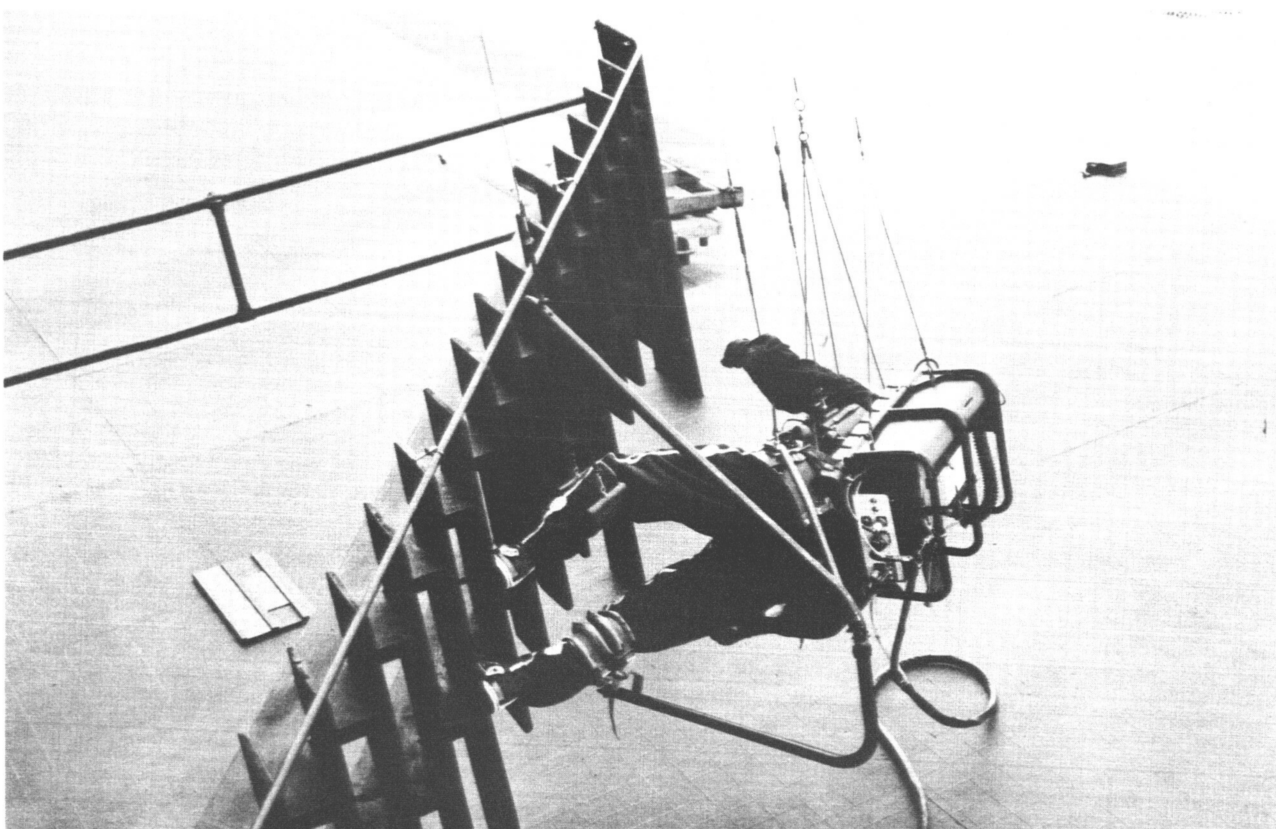


Figure 196. – Illustration of test arrangement for test series 1180.

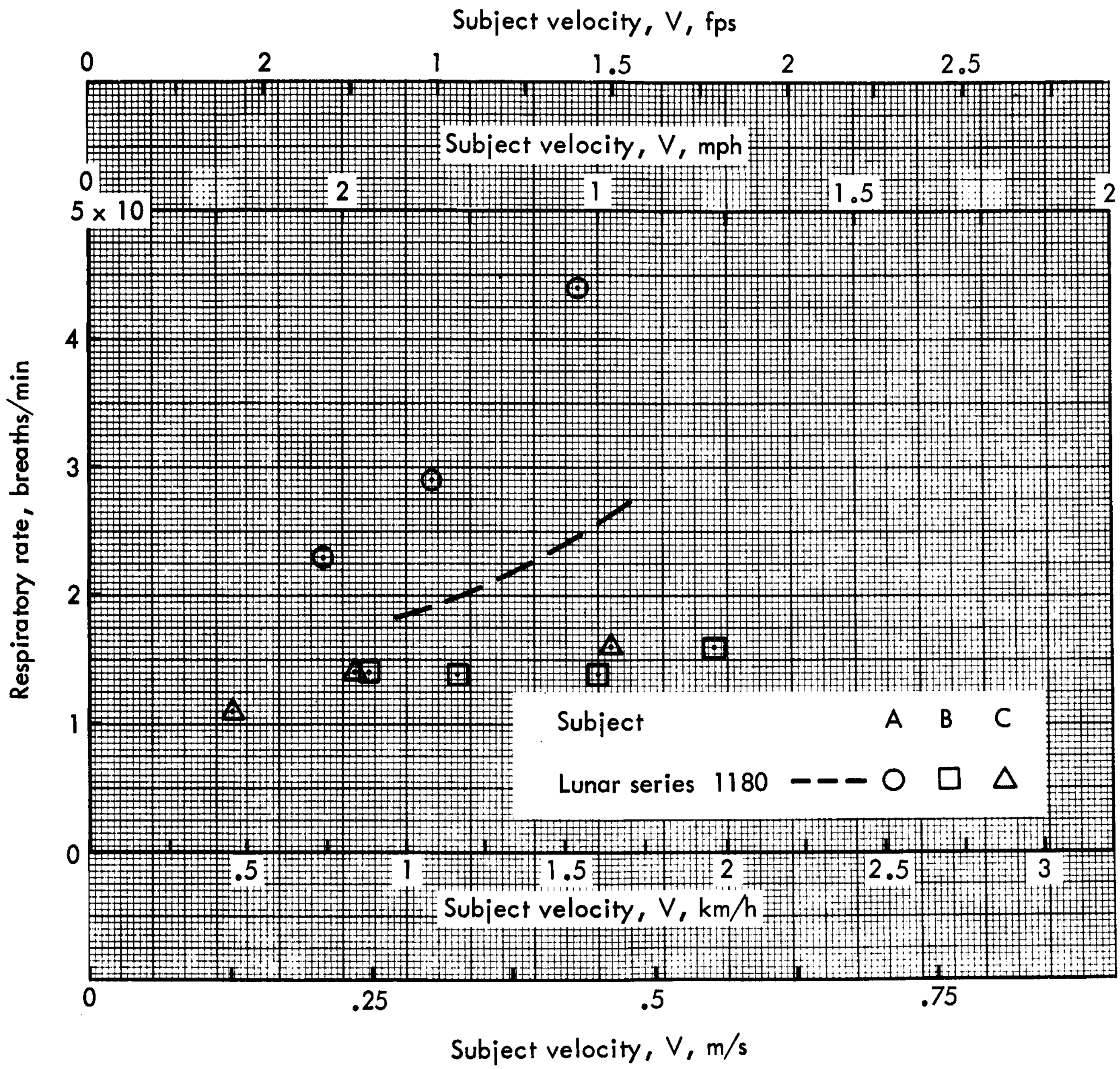


Figure 197. – Average respiratory rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

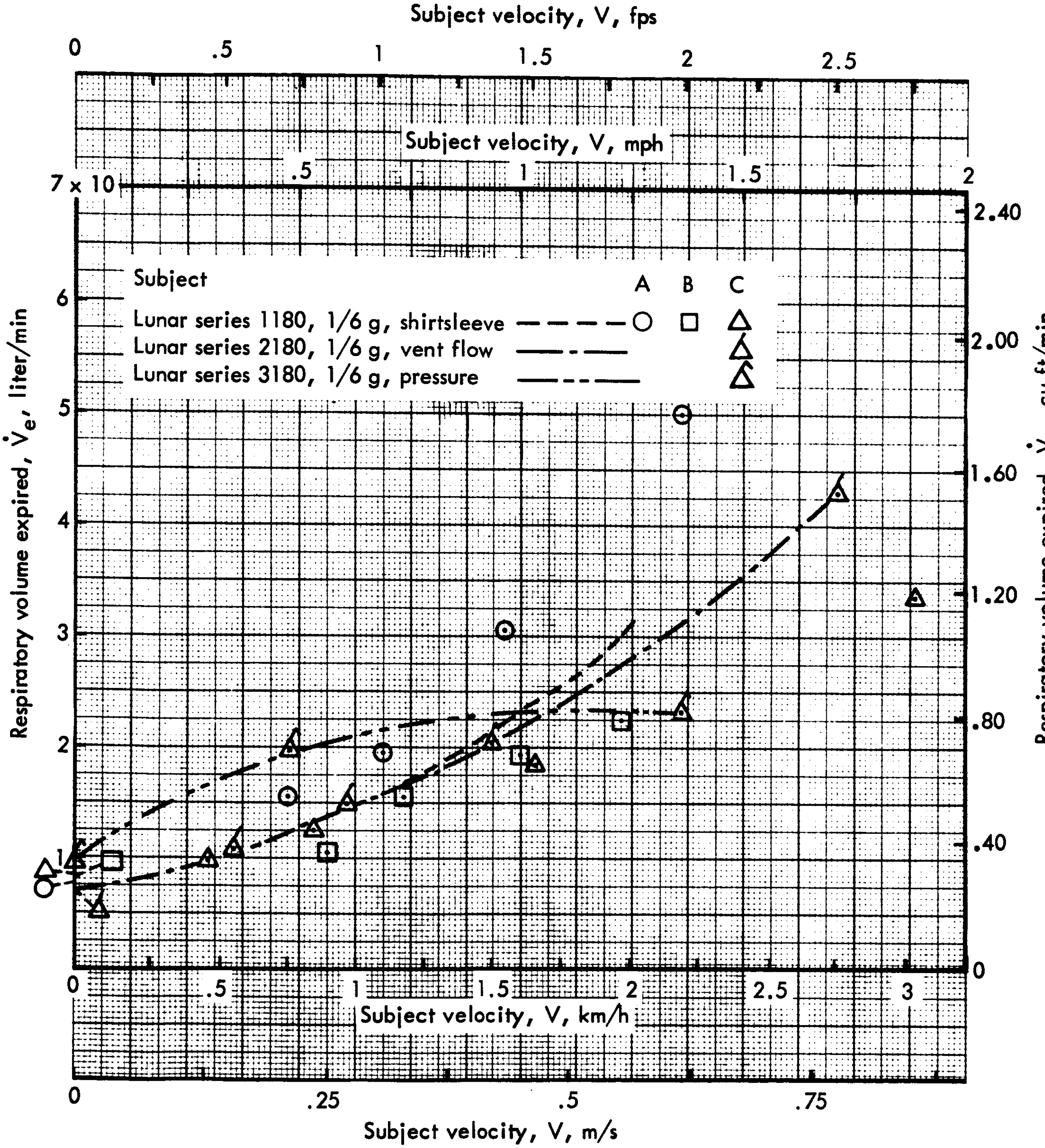


Figure 198. – Average mean respiratory volume versus subject velocity stair stepping.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

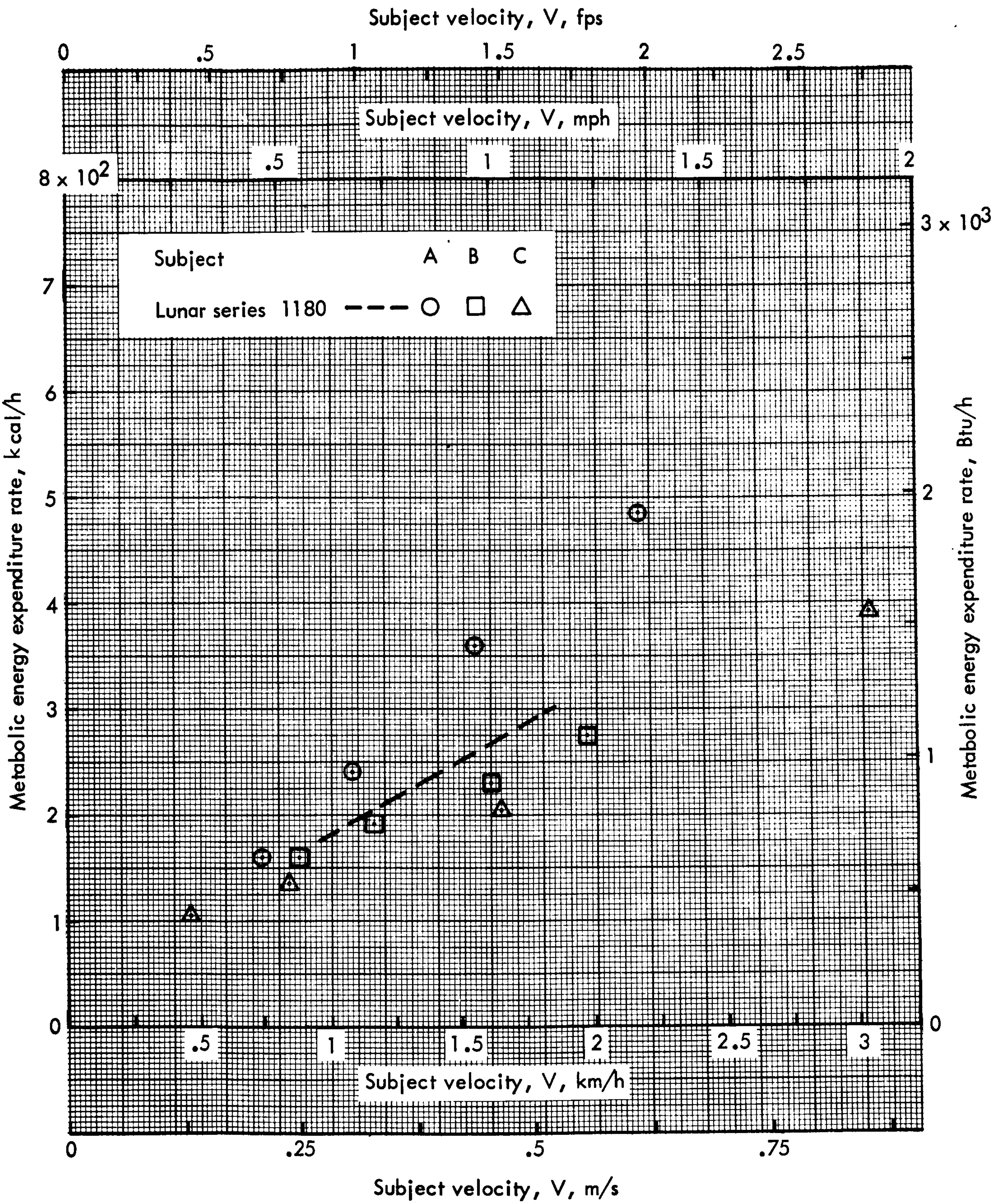


Figure 199. – Average metabolic energy expenditure rate versus subject velocity in stair stepping.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

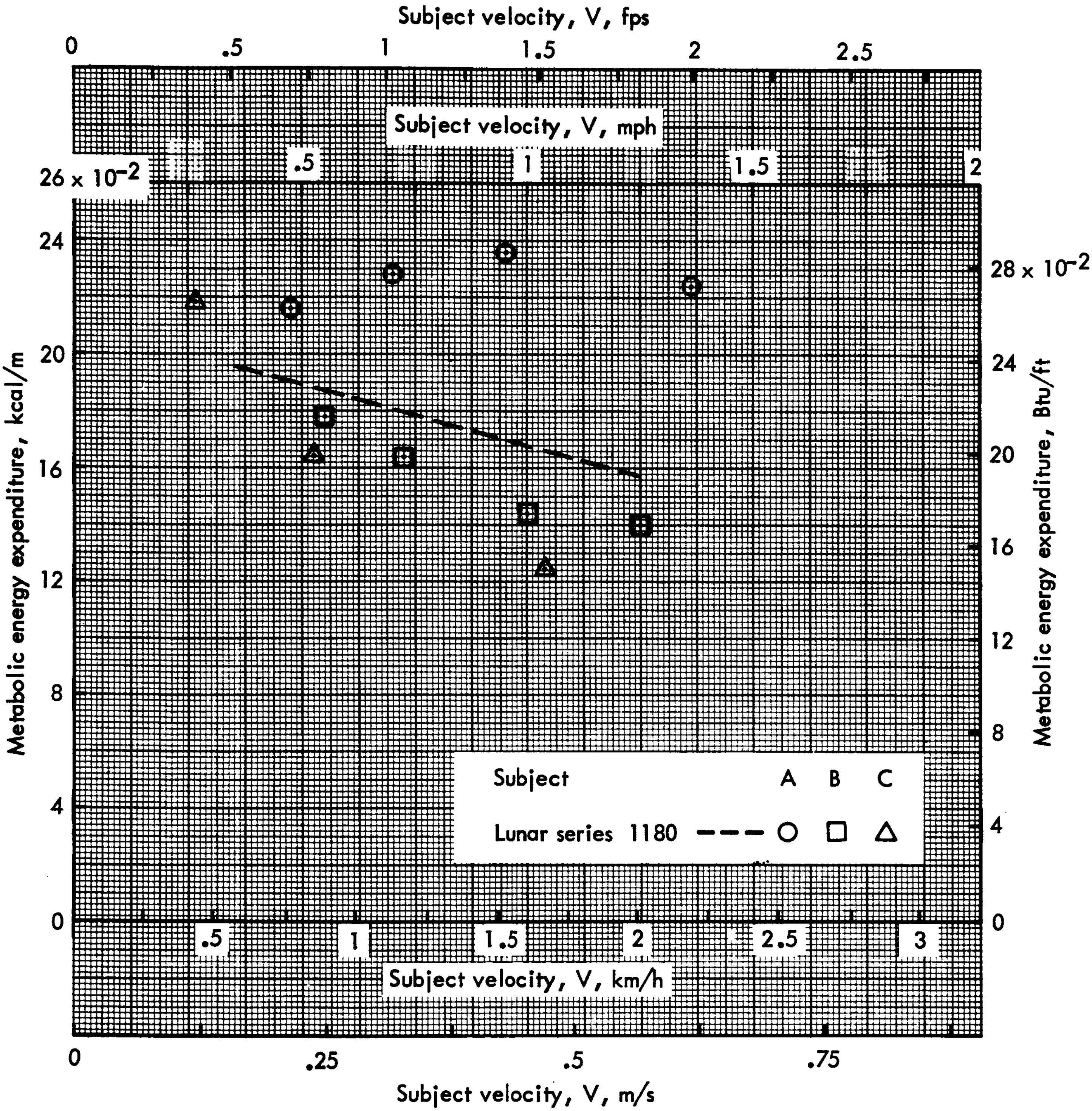


Figure 200. – Average metabolic energy expenditure per unit length versus subject velocity stair stepping.

Test Conditions: 1/6, shirtsleeve, susp. gear, pack I

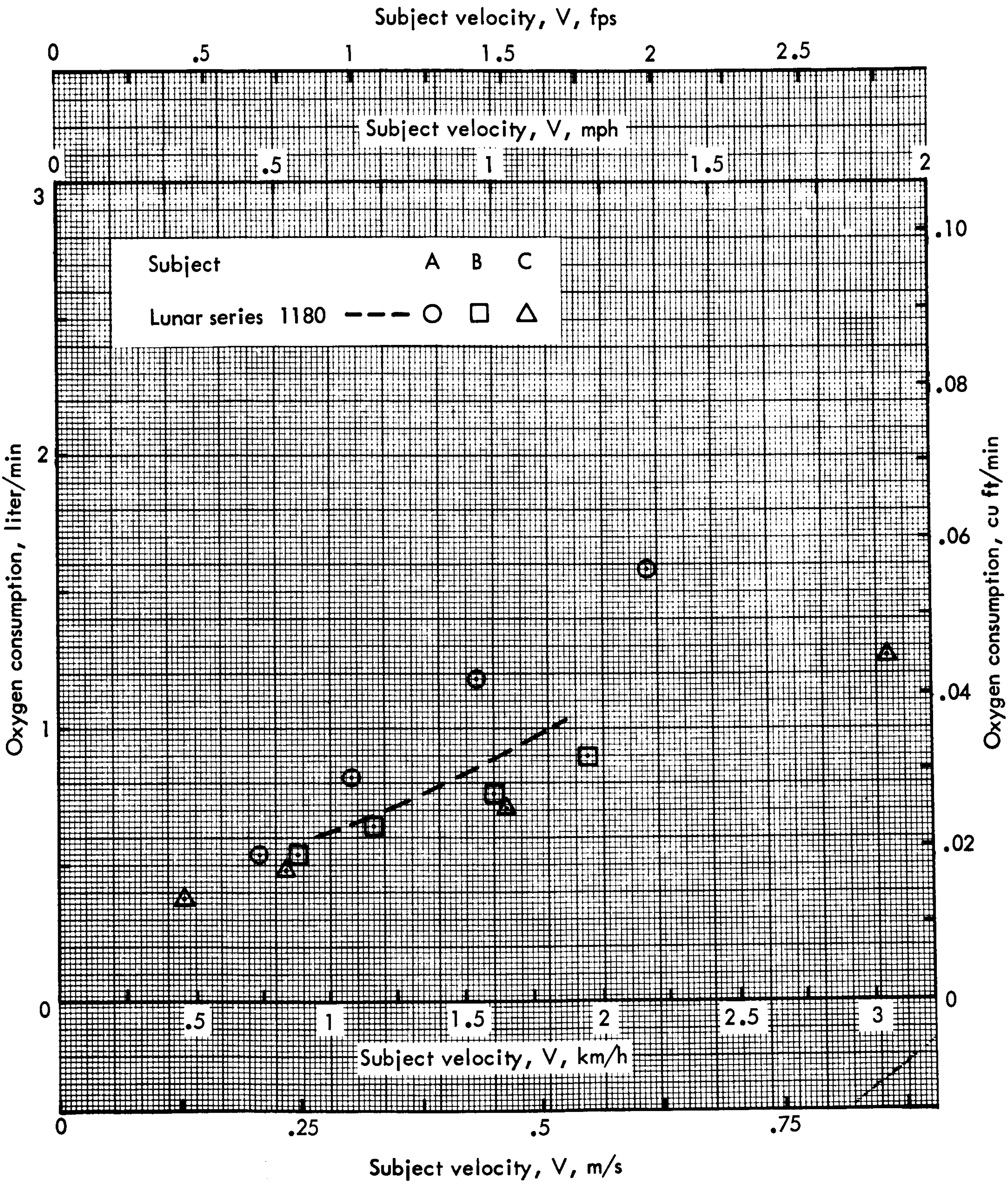


Figure 201. – Average oxygen consumption versus subject velocity stair stepping. Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

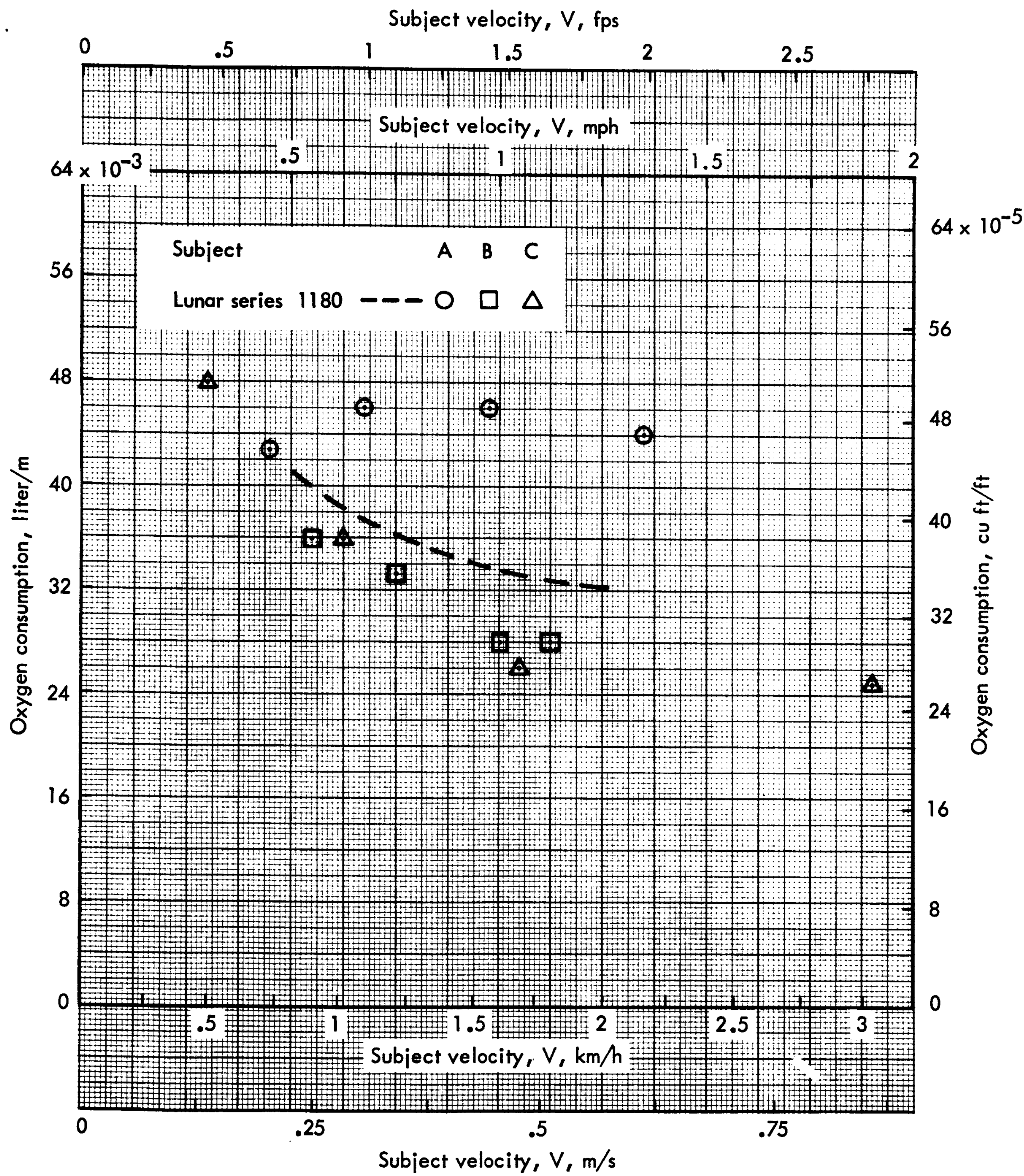


Figure 202. – Average oxygen consumption per unit length versus subject velocity stair stepping.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

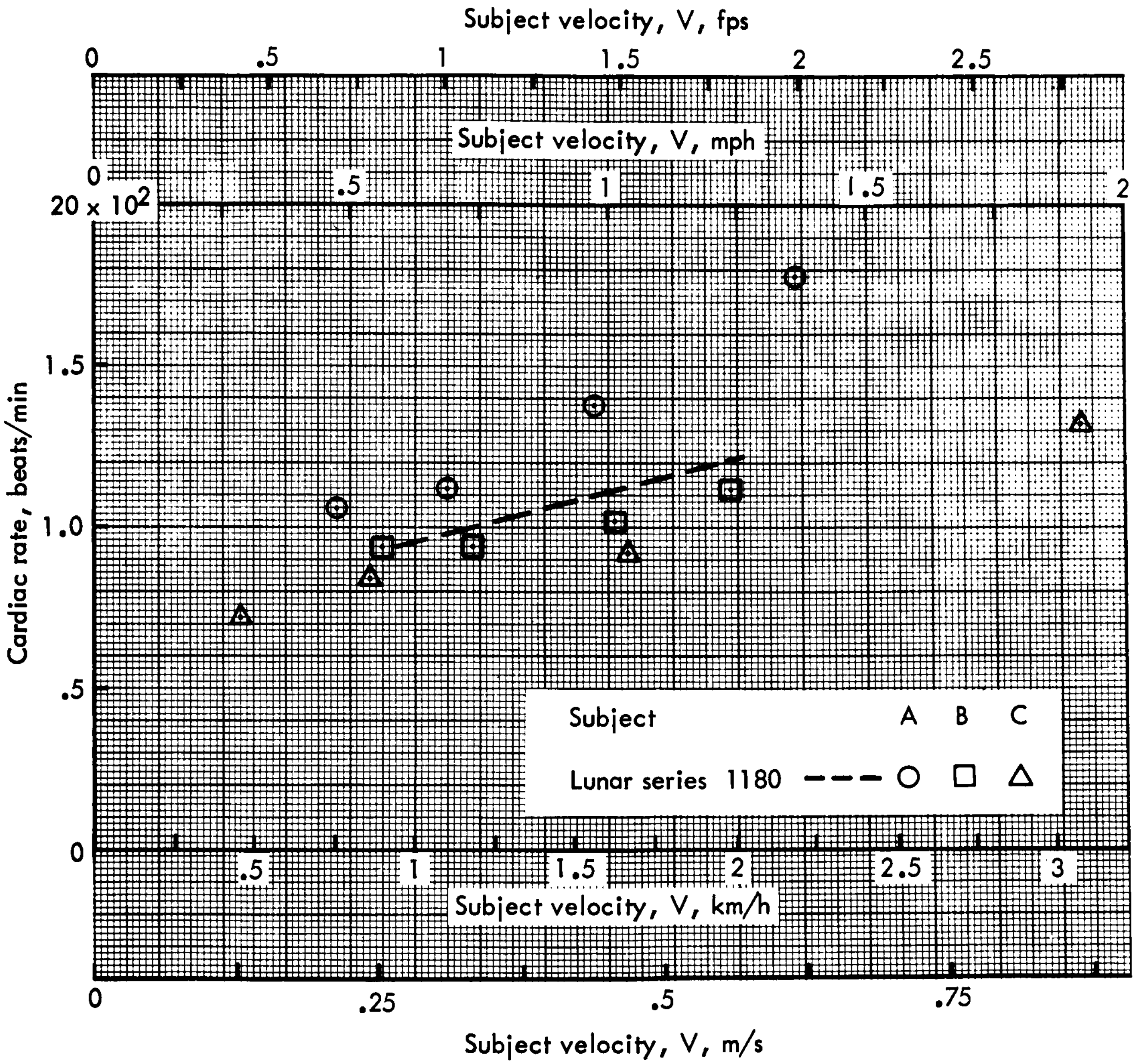


Figure 203. – Average cardiac rate versus subject velocity stair stepping. Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

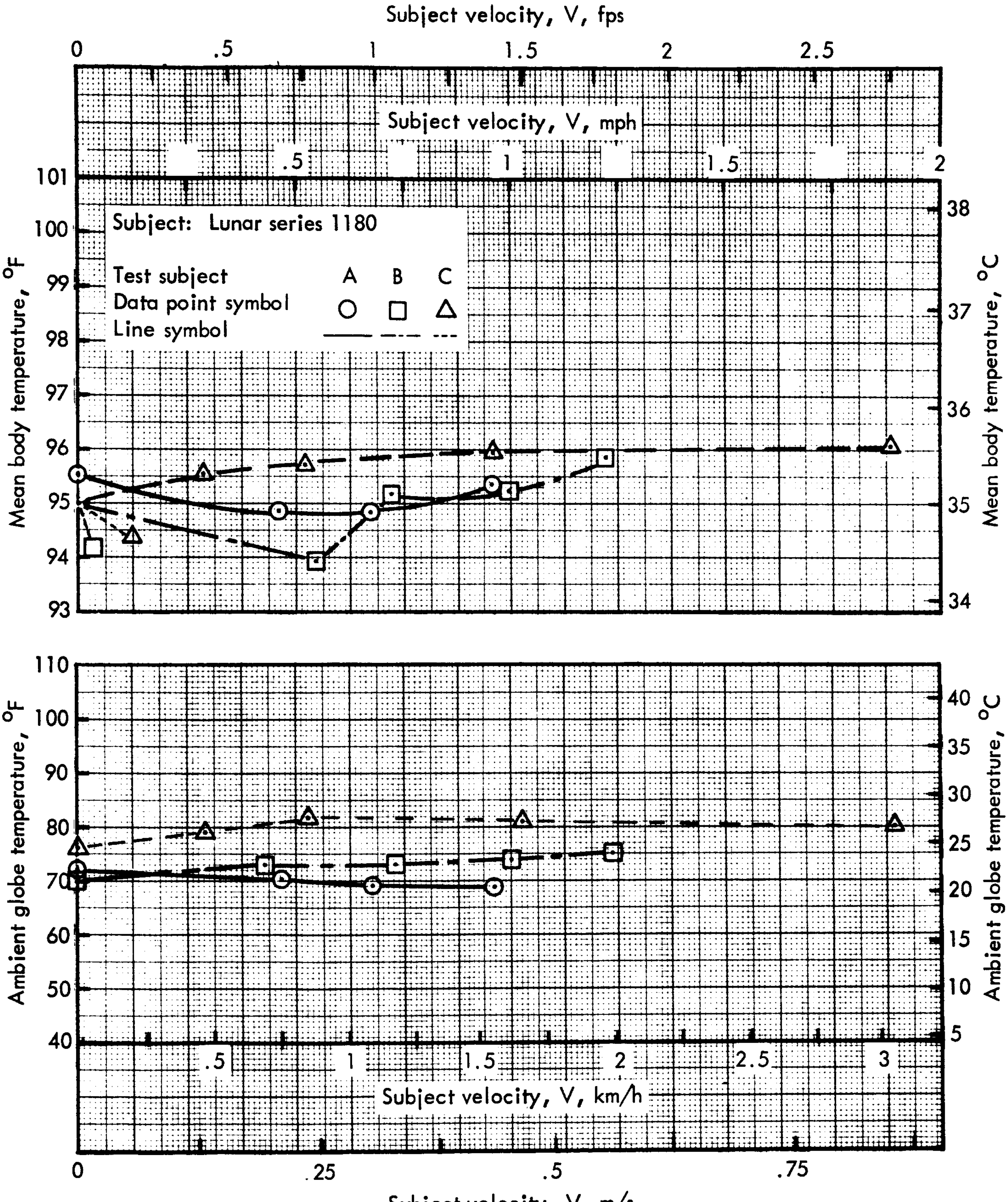


Figure 204. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity stair stepping.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2180

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	
Instrument Pack I		Instrument Pack II	x
Work Activity	stair stepping	Work Variable	ascend. & descend at 35
Gravity: Lunar	x	Earth	

Test Location: *

1/6 g Treadmill		One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			5

Respiration,	respiratory rate	Figure 206
	respiratory volume expired	Figure 198
Metabolism,	metabolic energy expenditure rate	Figure 207
	metabolic energy expenditure rate per unit length	Figure 208
	oxygen consumption	Figure 209
	oxygen consumption per unit length	Figure 210
Cardiovascular function,	cardiac rate	Figure 211
Body temperature,	mean body temperature	Figure 212
Pressure suit environmental data		Figure 213

Comments:

The arrangement for the tests conducted in this series is shown in Figure 205 .

*See Test 1180 Sheet.

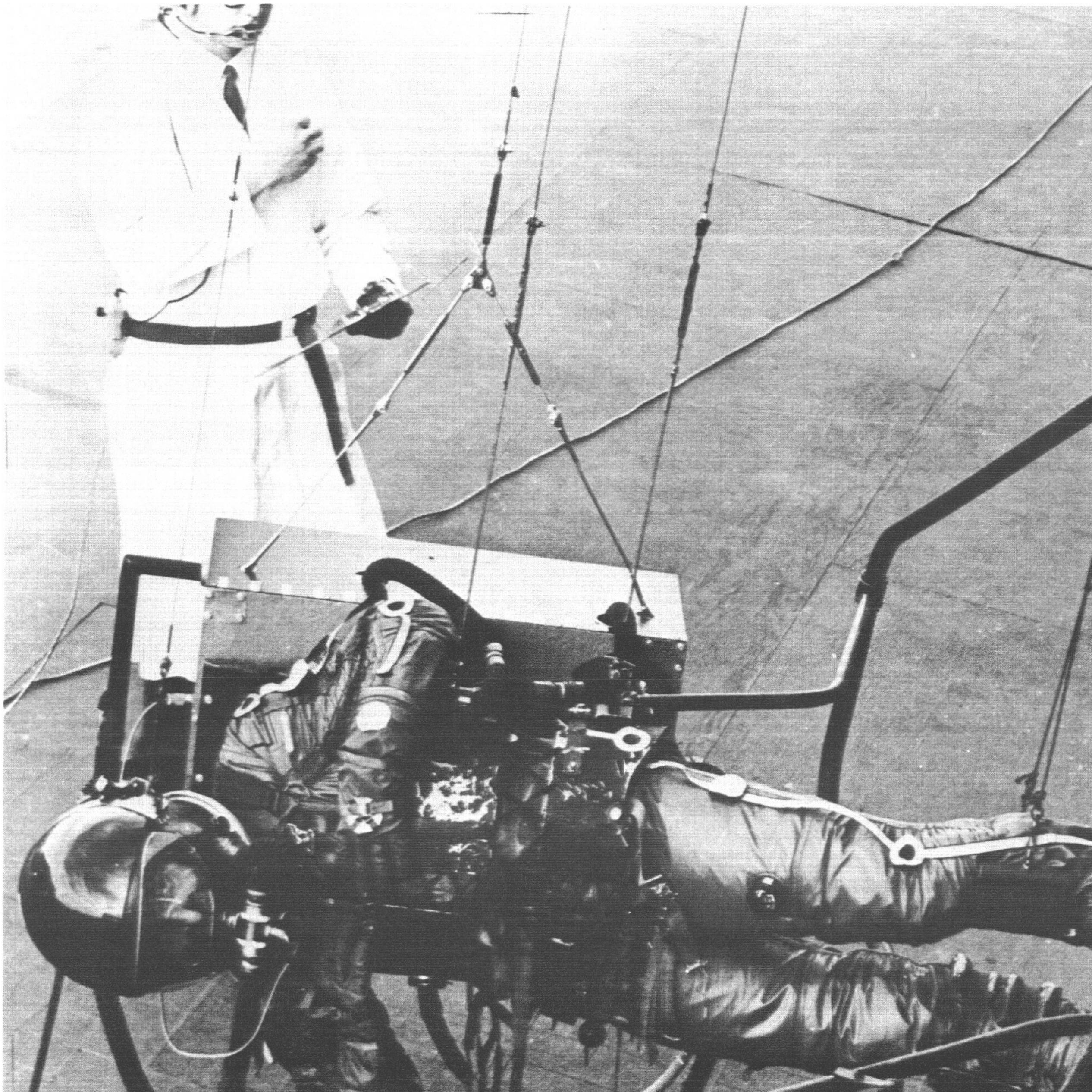


Figure 205. - Illustration of test arrangement for test series 2180

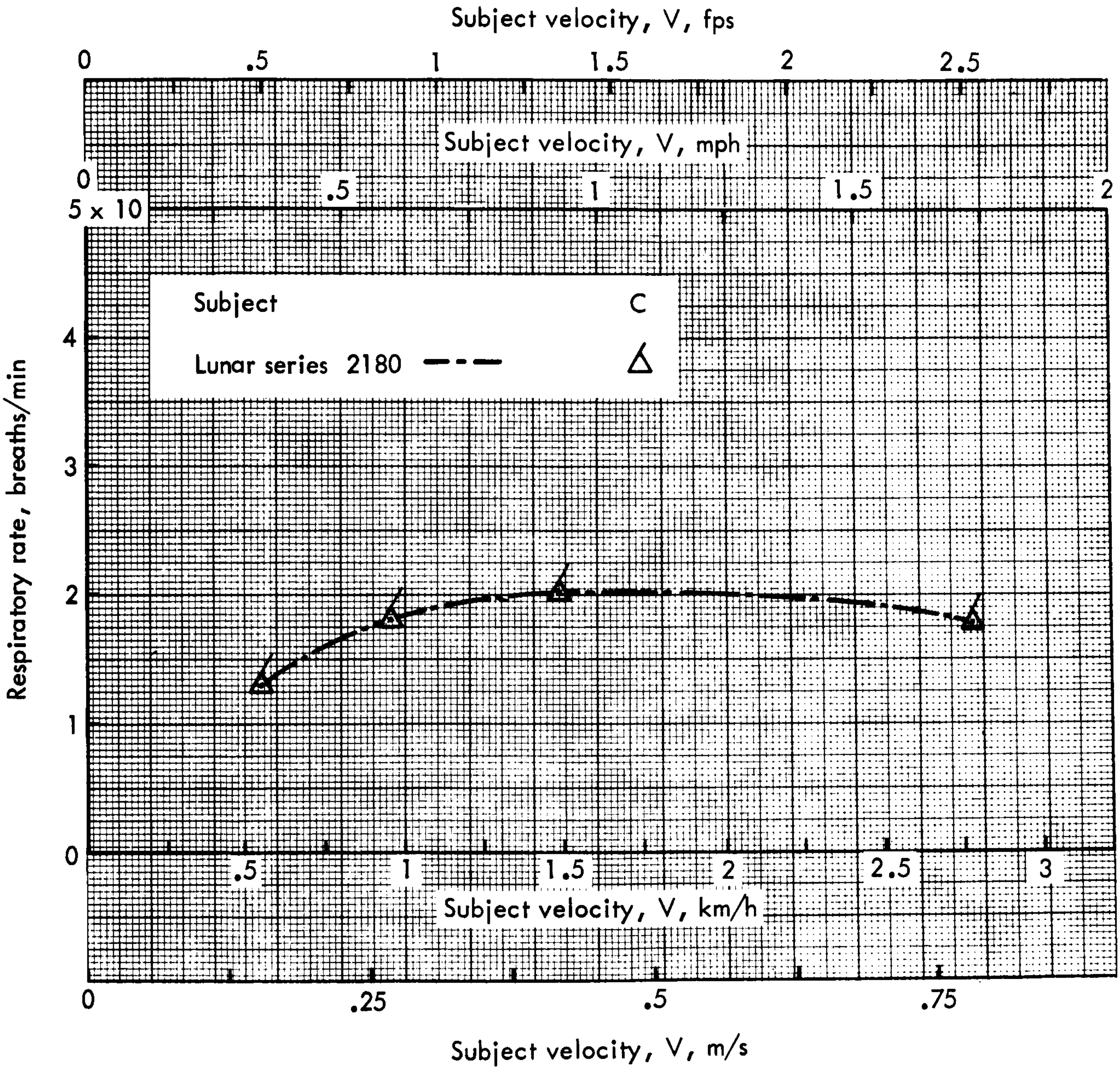


Figure 206. – Respiratory rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

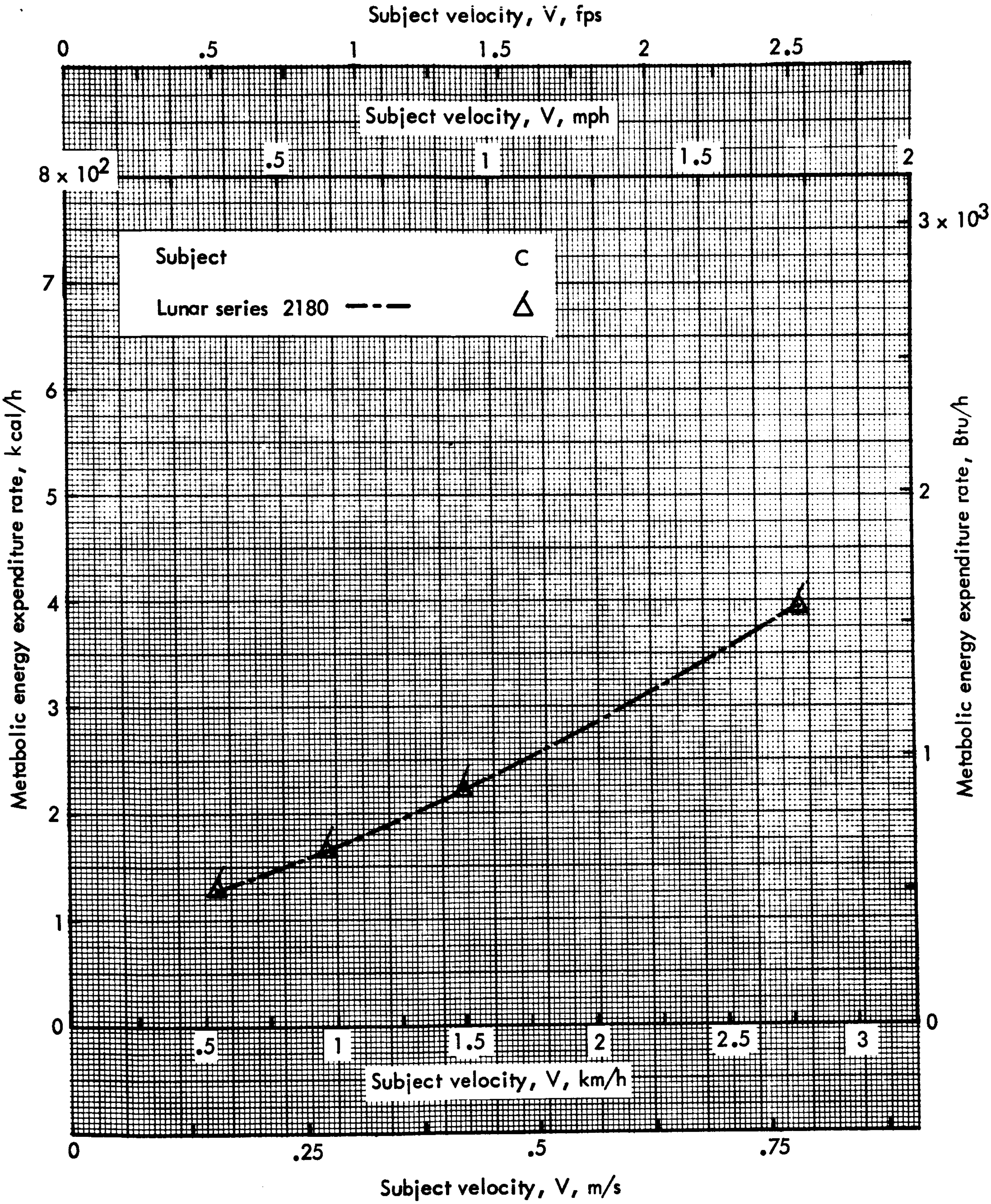


Figure 207. – Metabolic energy expenditure rate versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

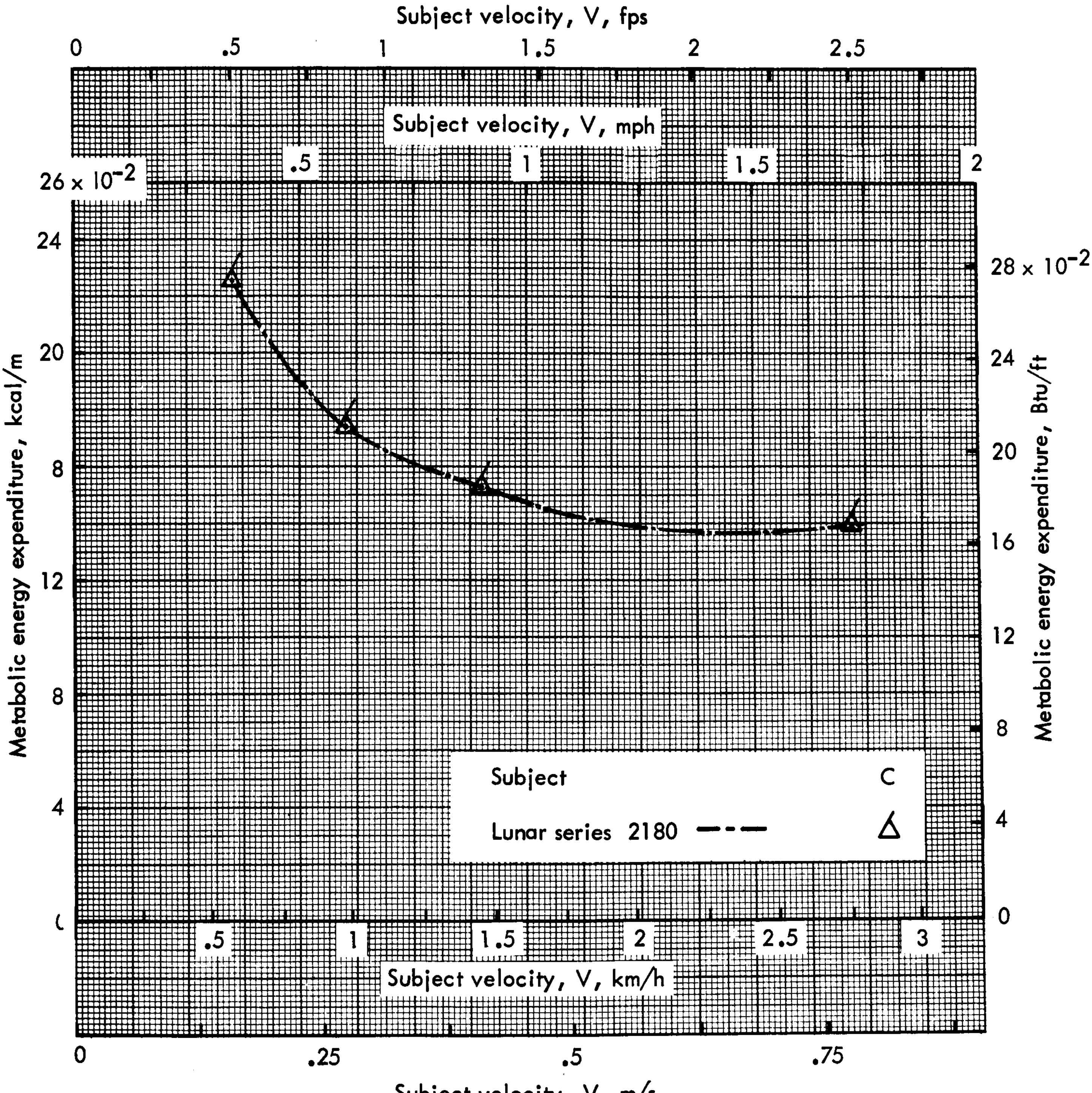


Figure 208. – Metabolic energy expenditure per unit length versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

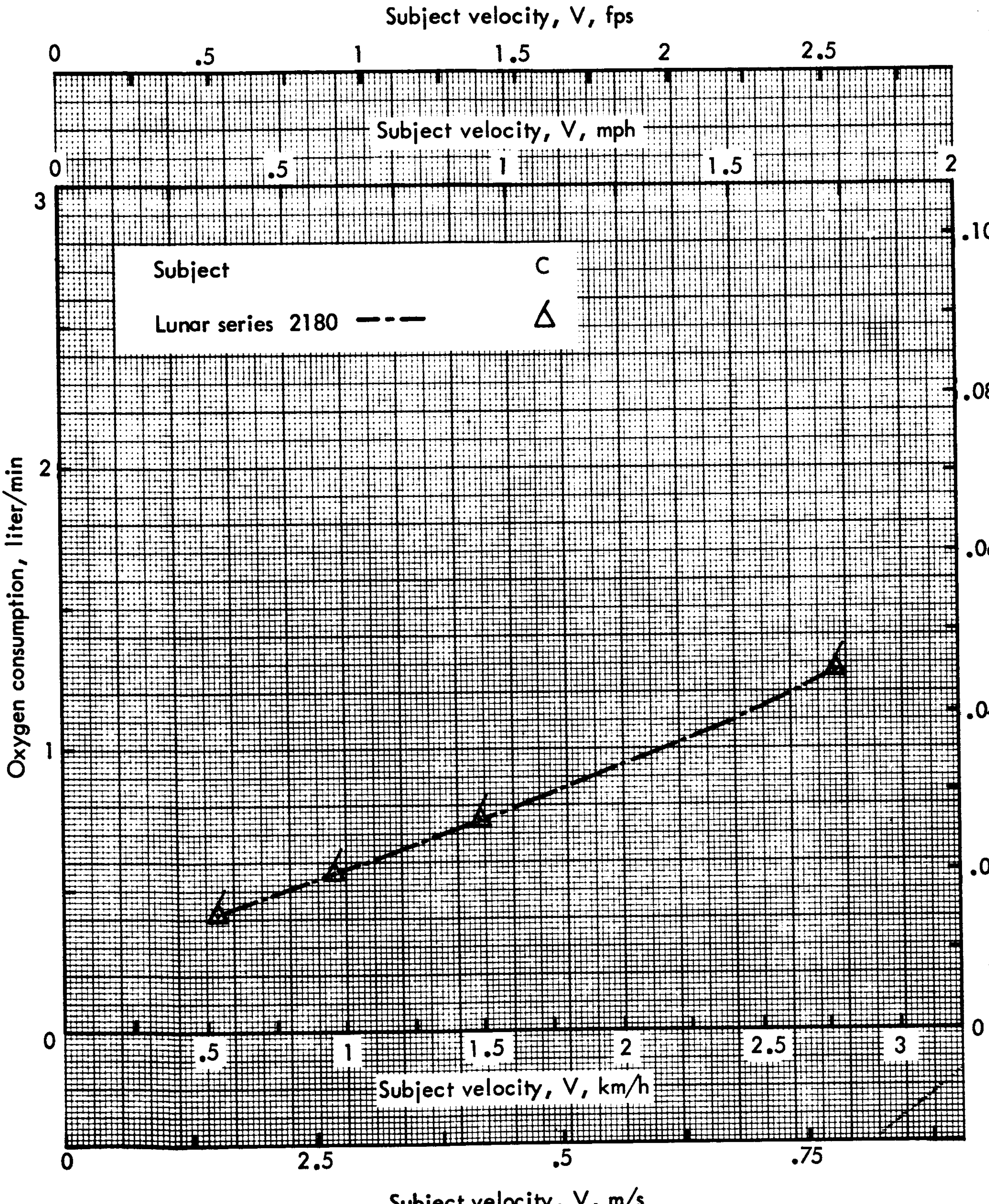


Figure 209. – Oxygen consumption versus subject velocity stair stepping. Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

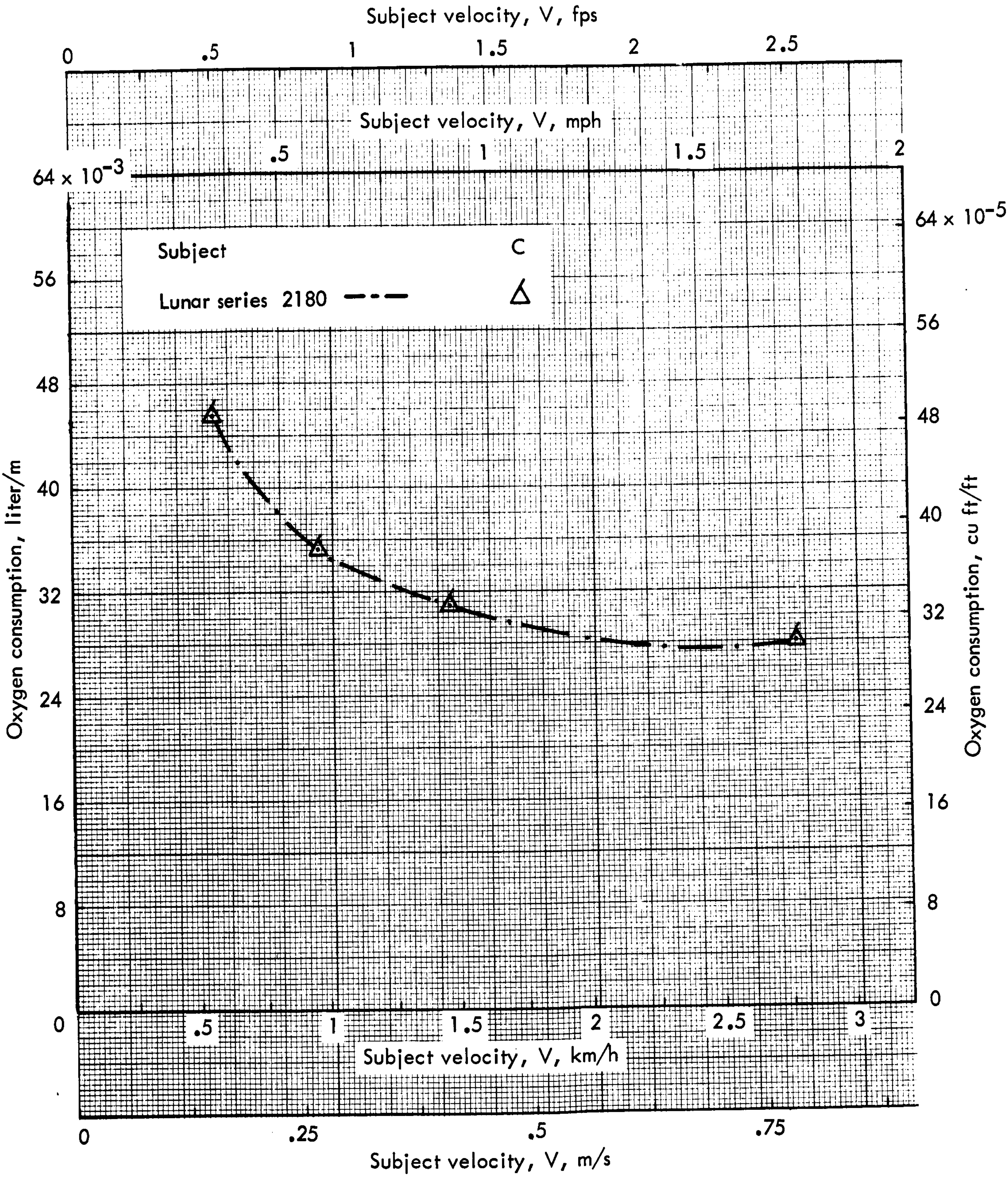


Figure 210. – Oxygen consumption per unit length versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

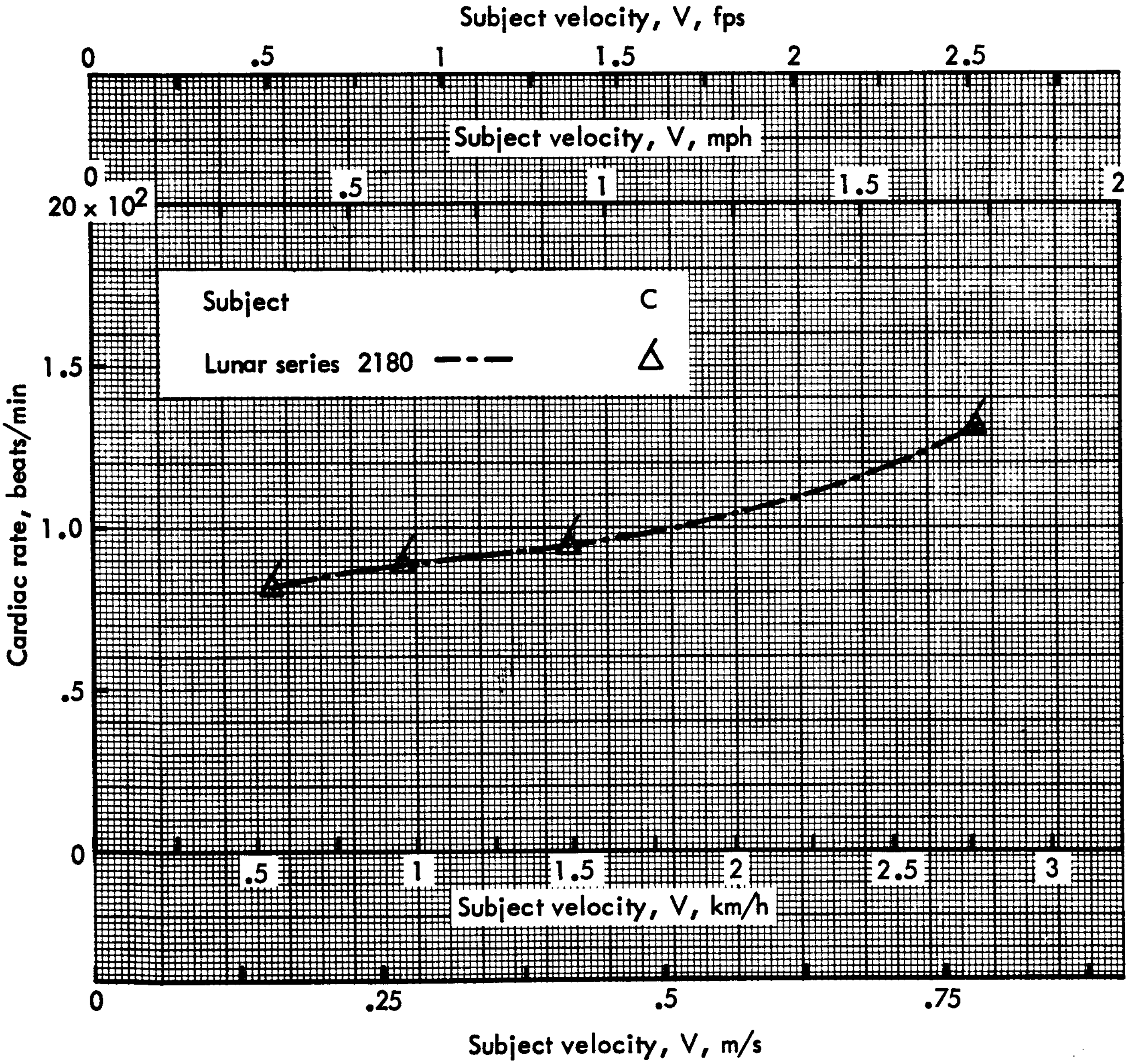


Figure 211. – Cardiac rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

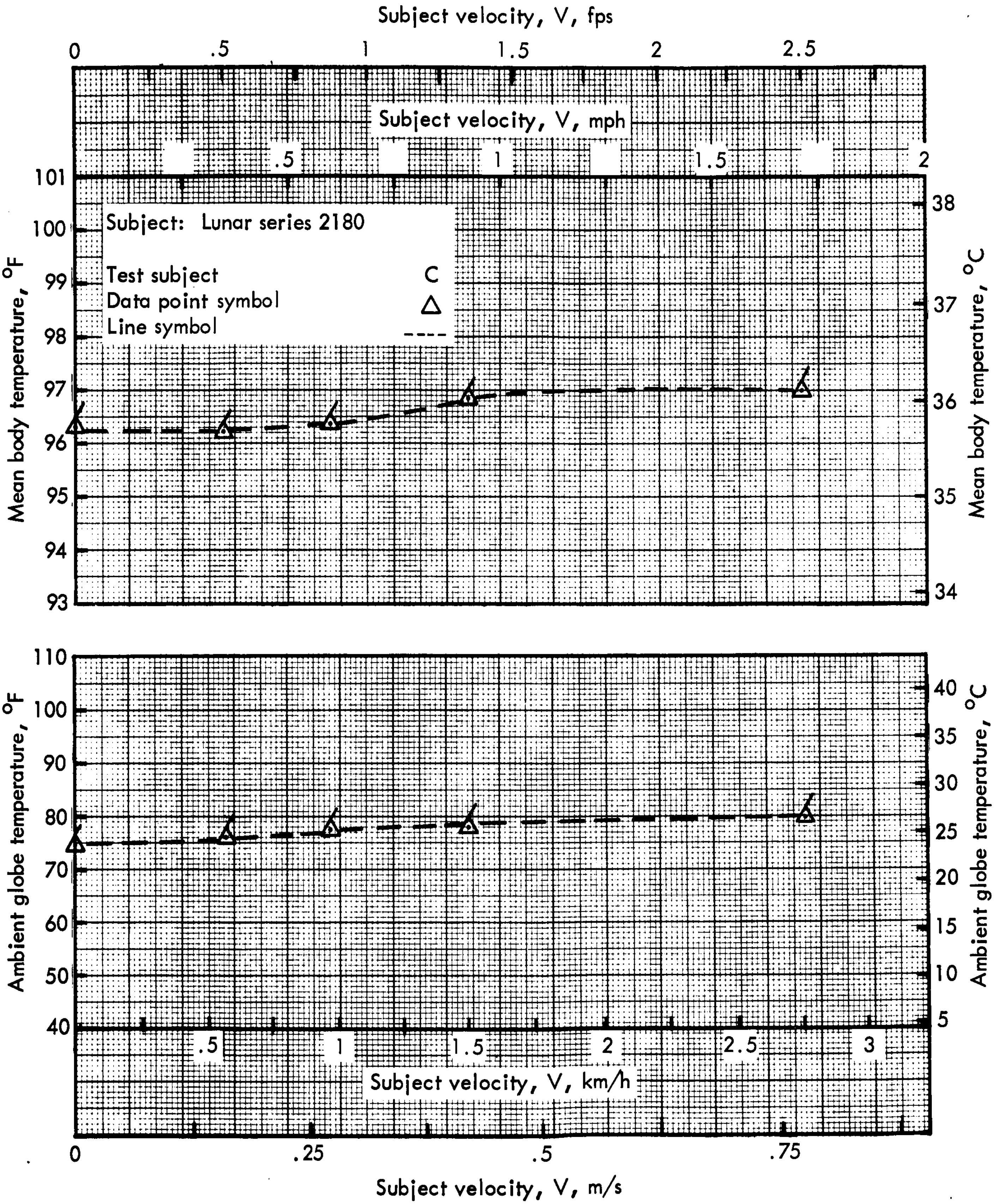


Figure 212. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

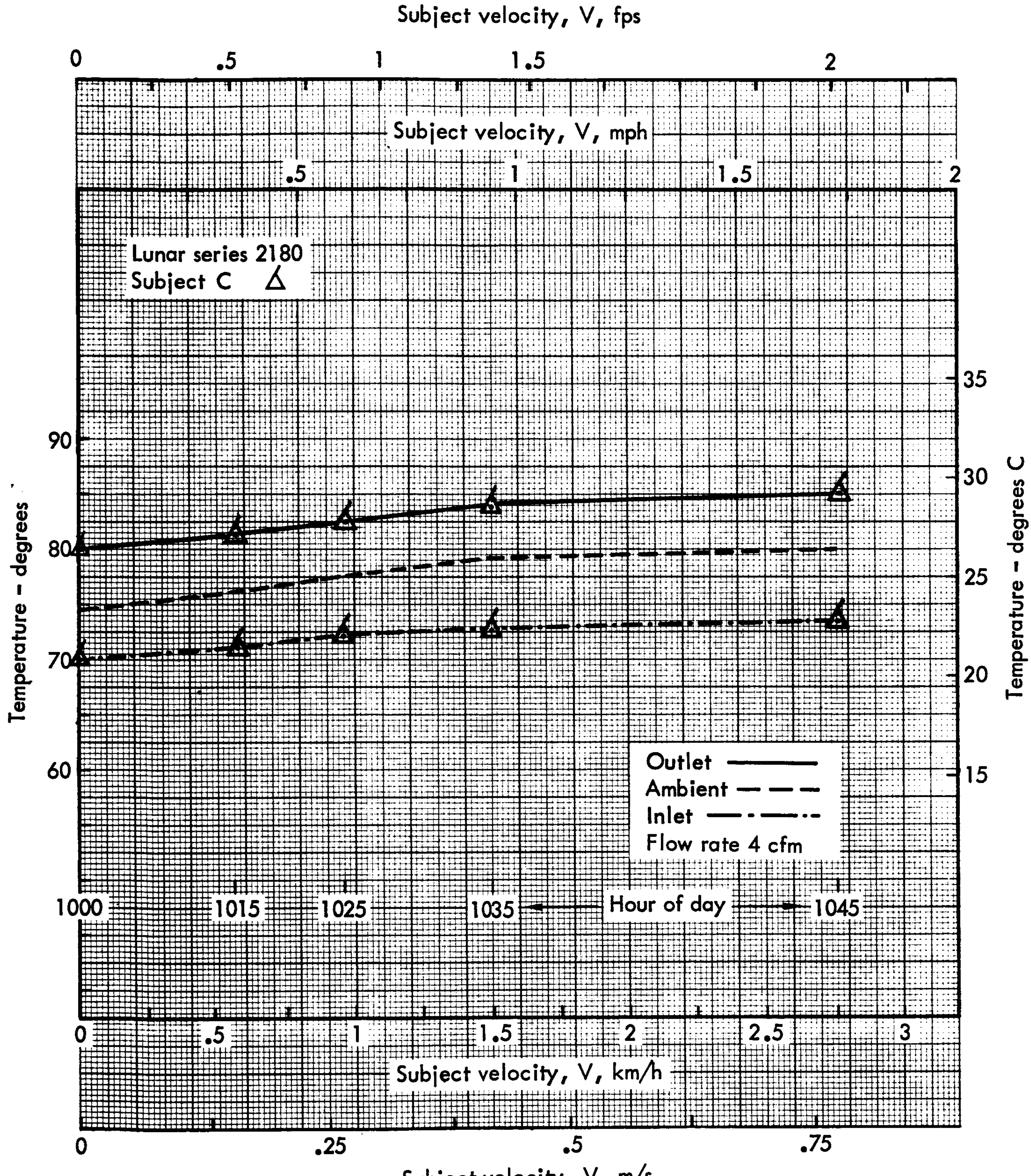


Figure 213. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity, stair stepping.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3180

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	stair stepping	Work Variable	ascend. & descend. at 35
Gravity: Lunar	x	Earth	

Test Location: *

1/6 g Treadmill		One g Treadmill	

Test Results:

	A	B	C
Results for Subject			x
Number of Tests			4

Respiration, respiratory rate	Figure 215**
respiratory volume expired	Figure 198
Metabolism, metabolic energy expenditure rate	Figure 216
metabolic energy expenditure rate per unit length	Figure 217
oxygen consumption	Figure 218
oxygen consumption per unit length	Figure 219
Cardiovascular function, cardiac rate	Figure 220**
Body temperature, mean body temperature	Figure 221
Pressure suit environmental data	Figure 222

Comments:

The arrangement for the tests conducted in this series is shown in Figure 214

* See Test 1180 Sheet.

** Only one data point was obtained for subject C at .5 mph.

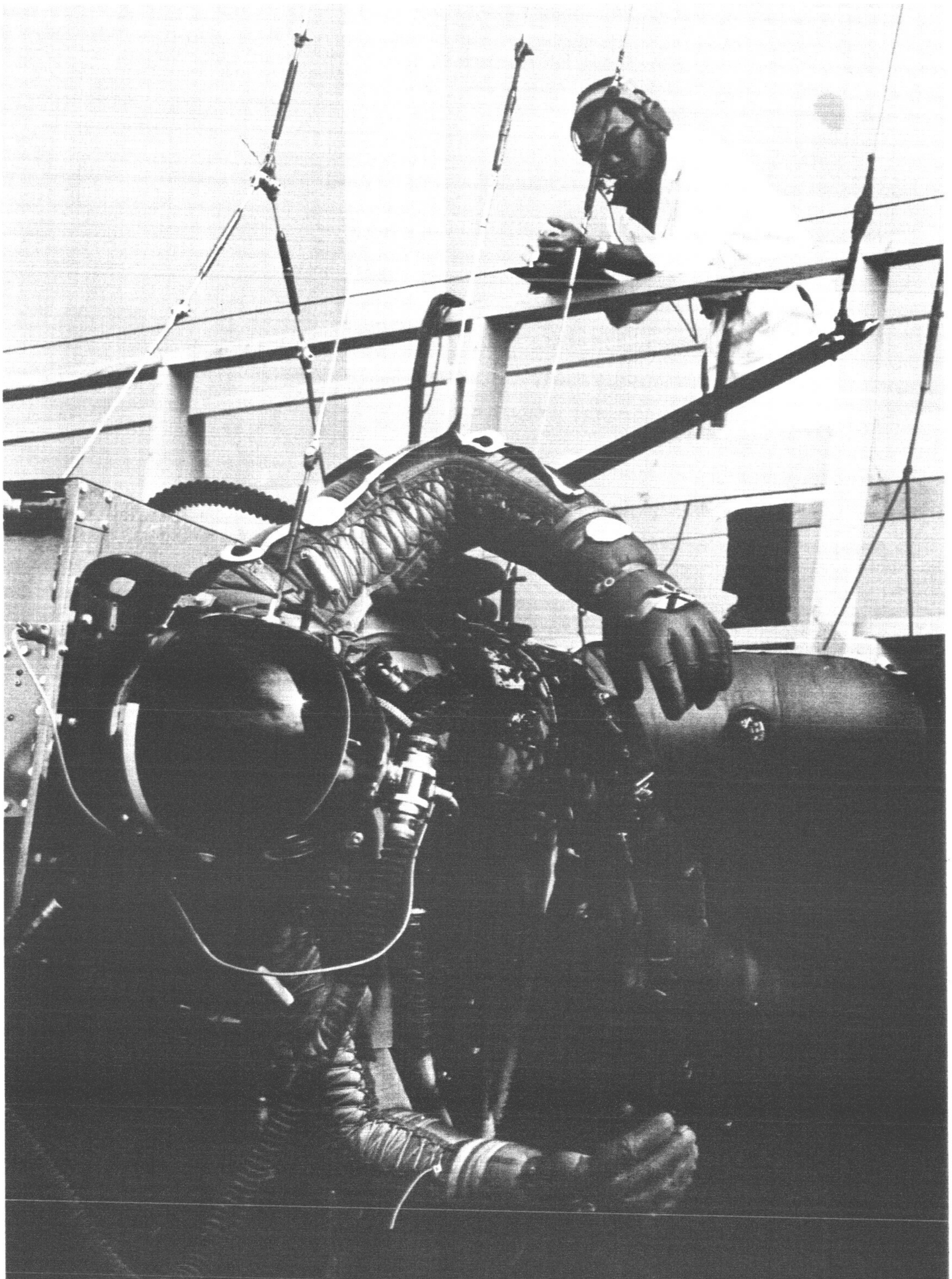


Figure 214. - Illustration of test arrangement for test series 3180

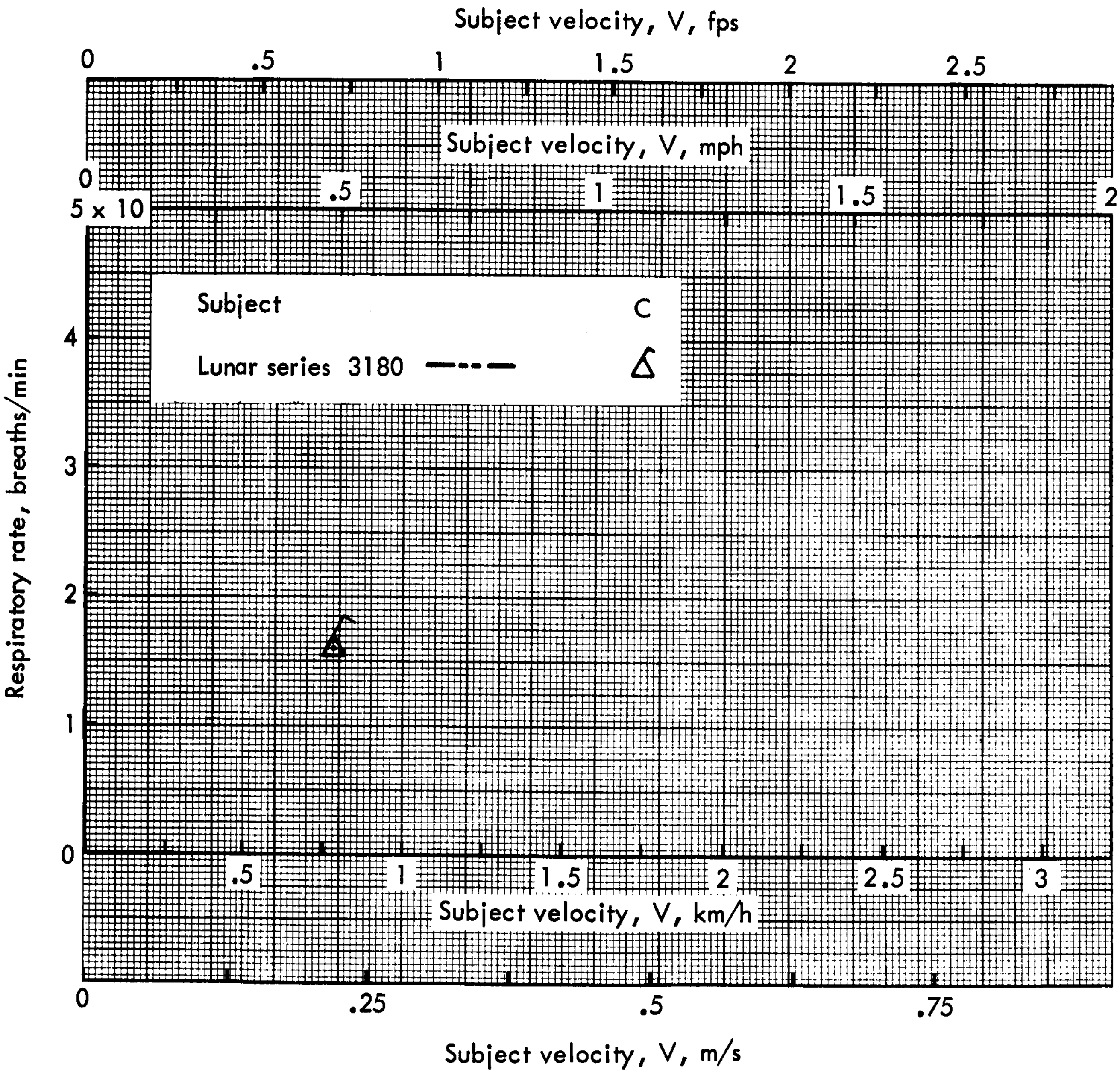


Figure 215. – Respiratory rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

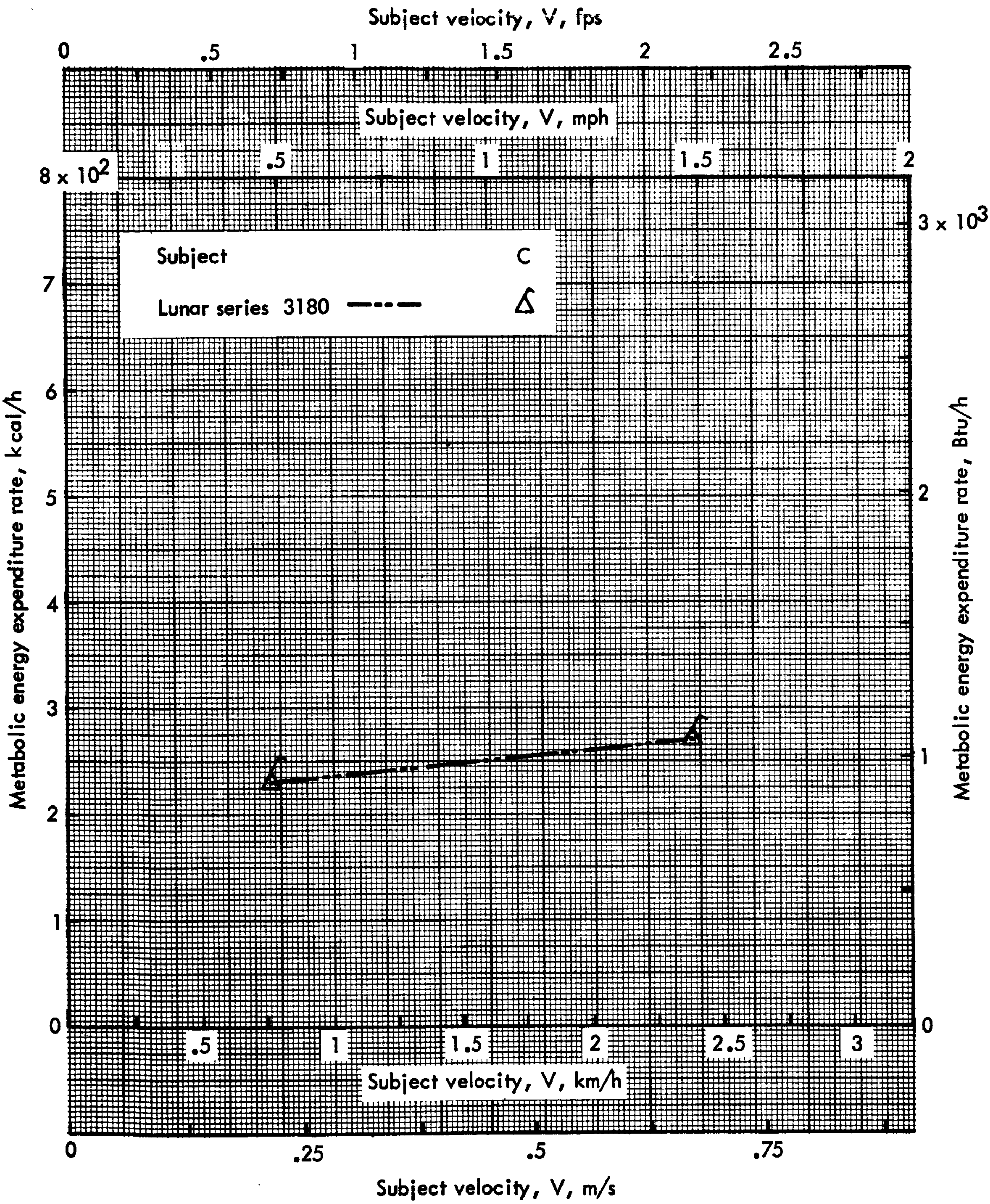


Figure 216. – Metabolic energy expenditure rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

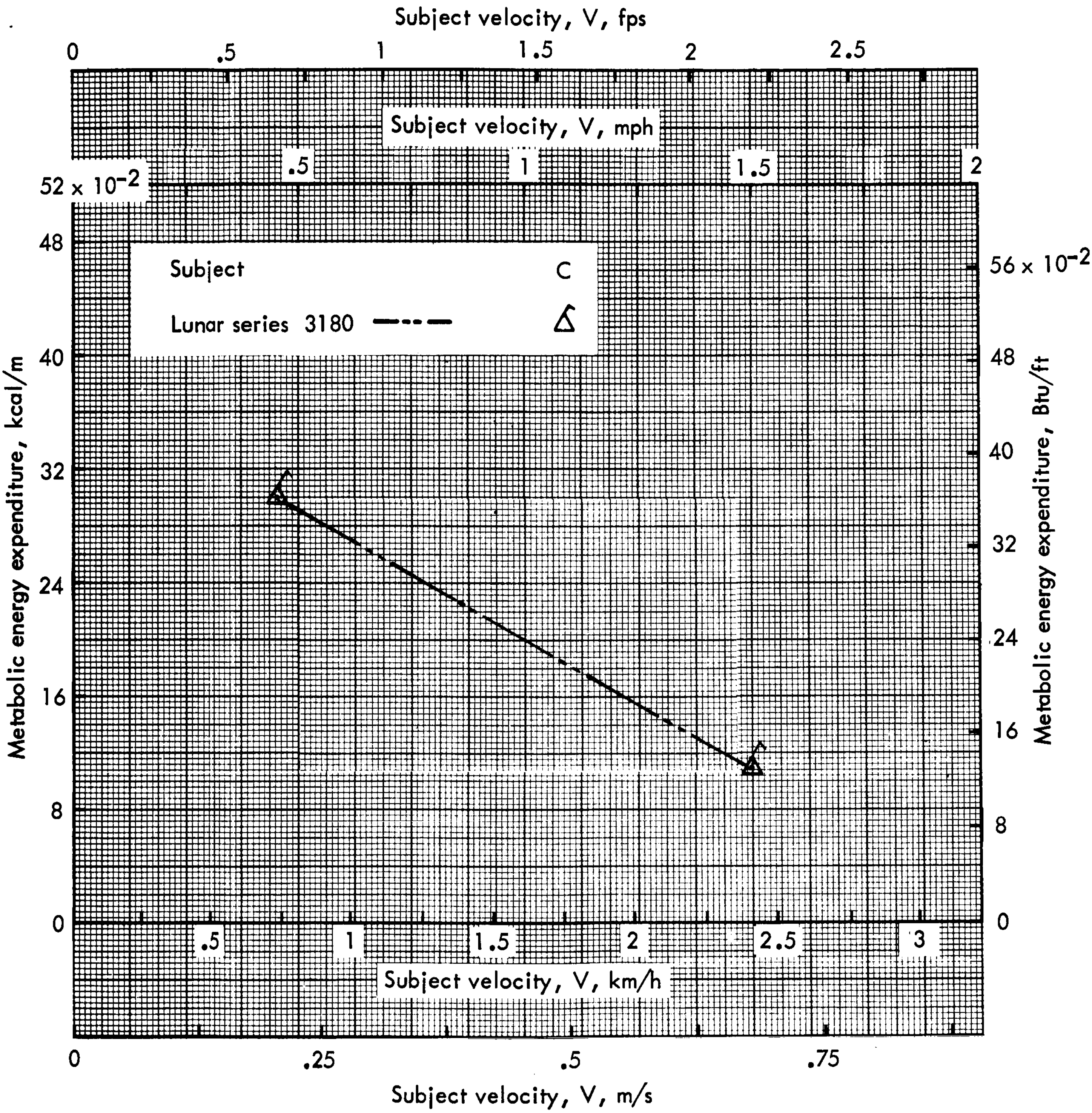


Figure 217. – Metabolic energy expenditure per unit length versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

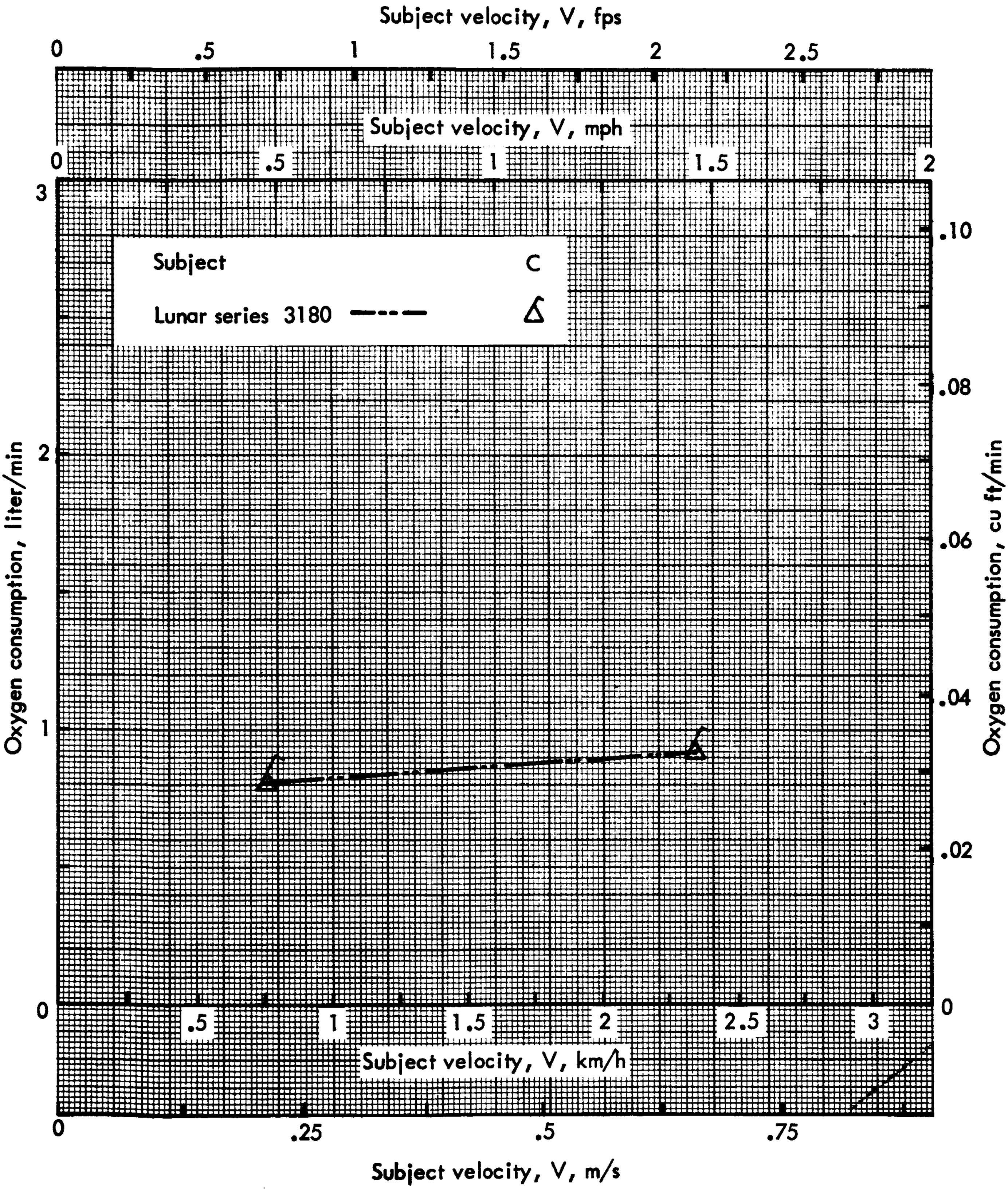


Figure 218. – Oxygen consumption versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

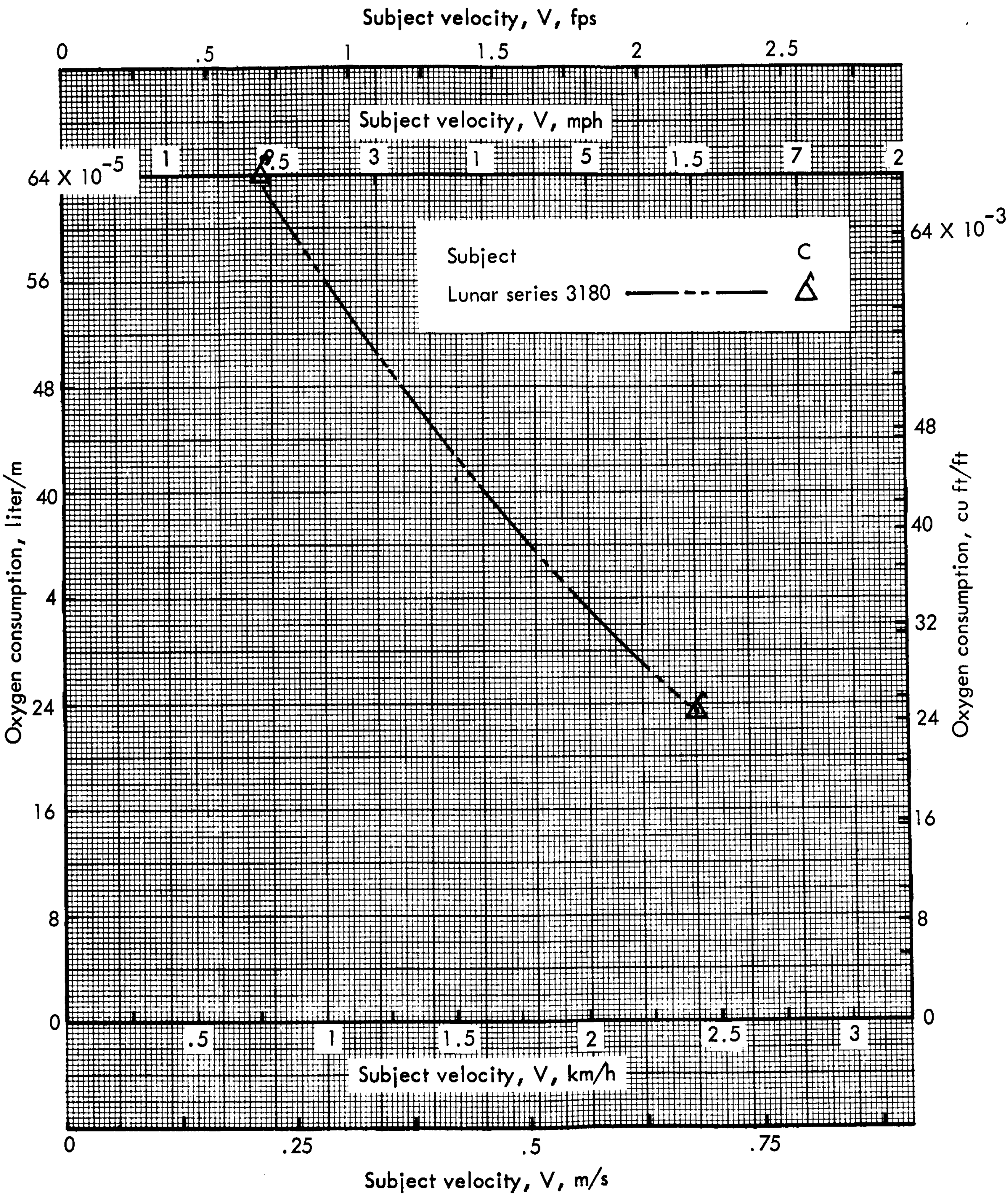


Figure 219. – Oxygen consumption per unit length versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

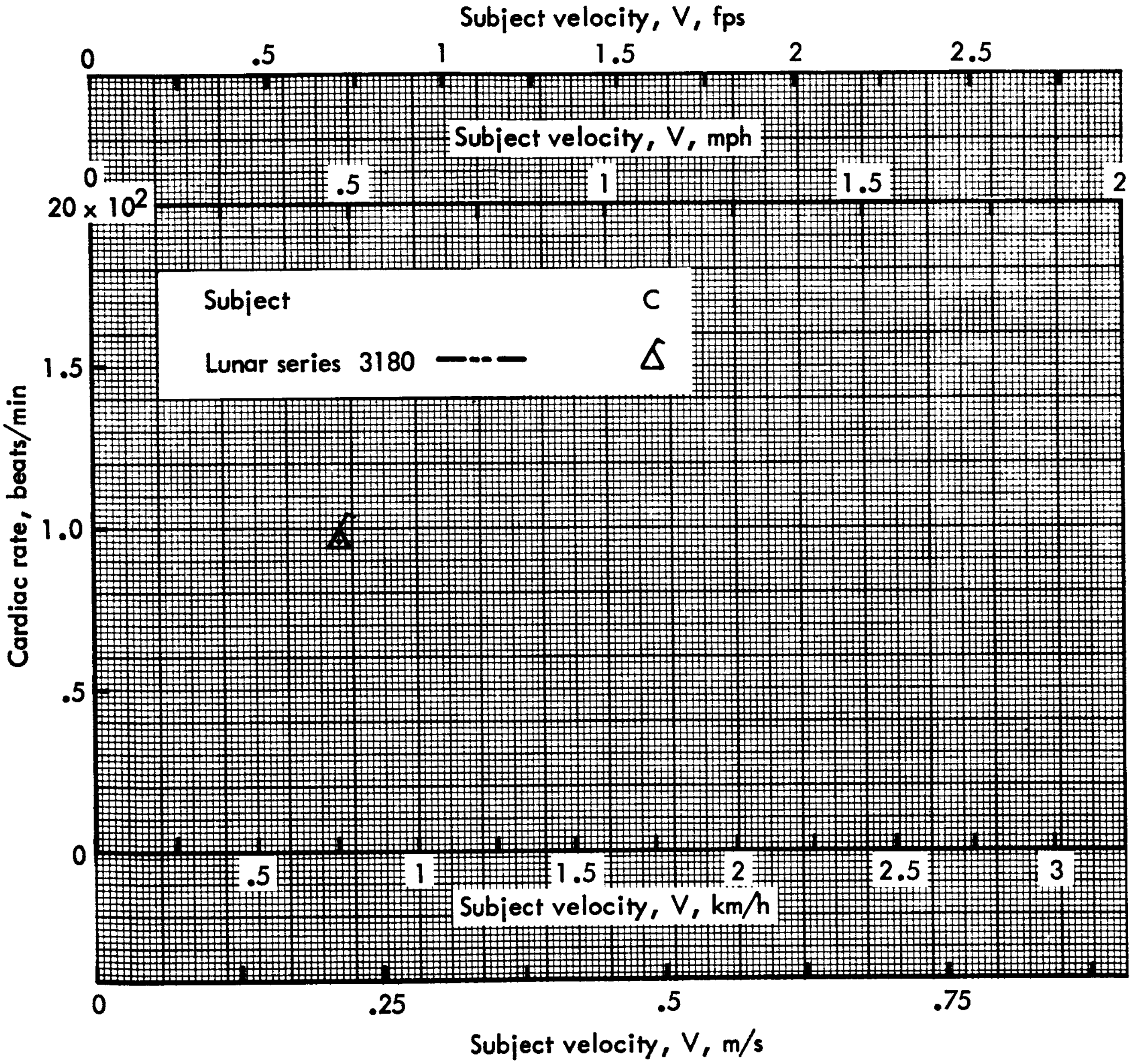


Figure 220. – Cardiac rate versus subject velocity stair stepping.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

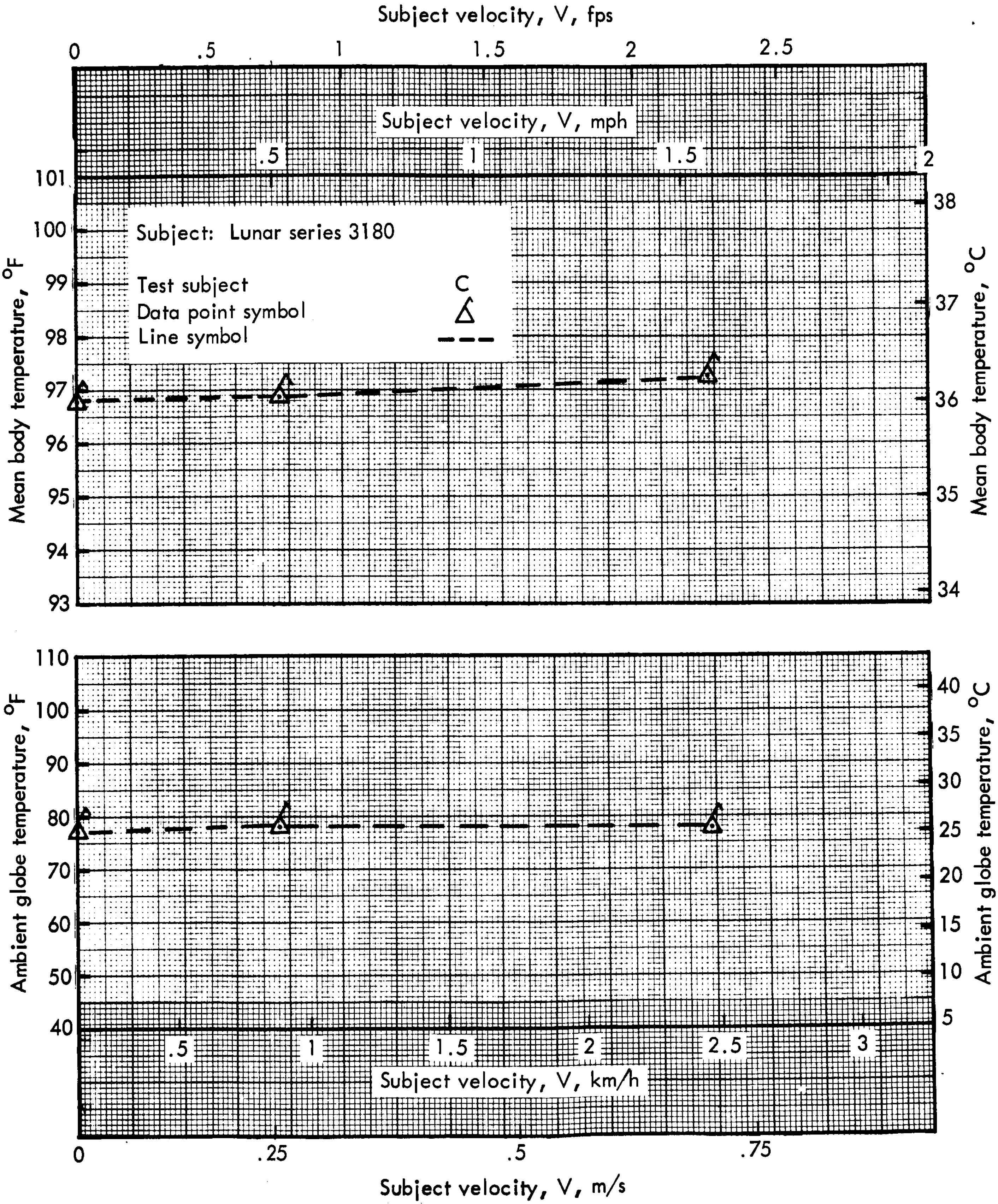


Figure 221. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity stair stepping

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

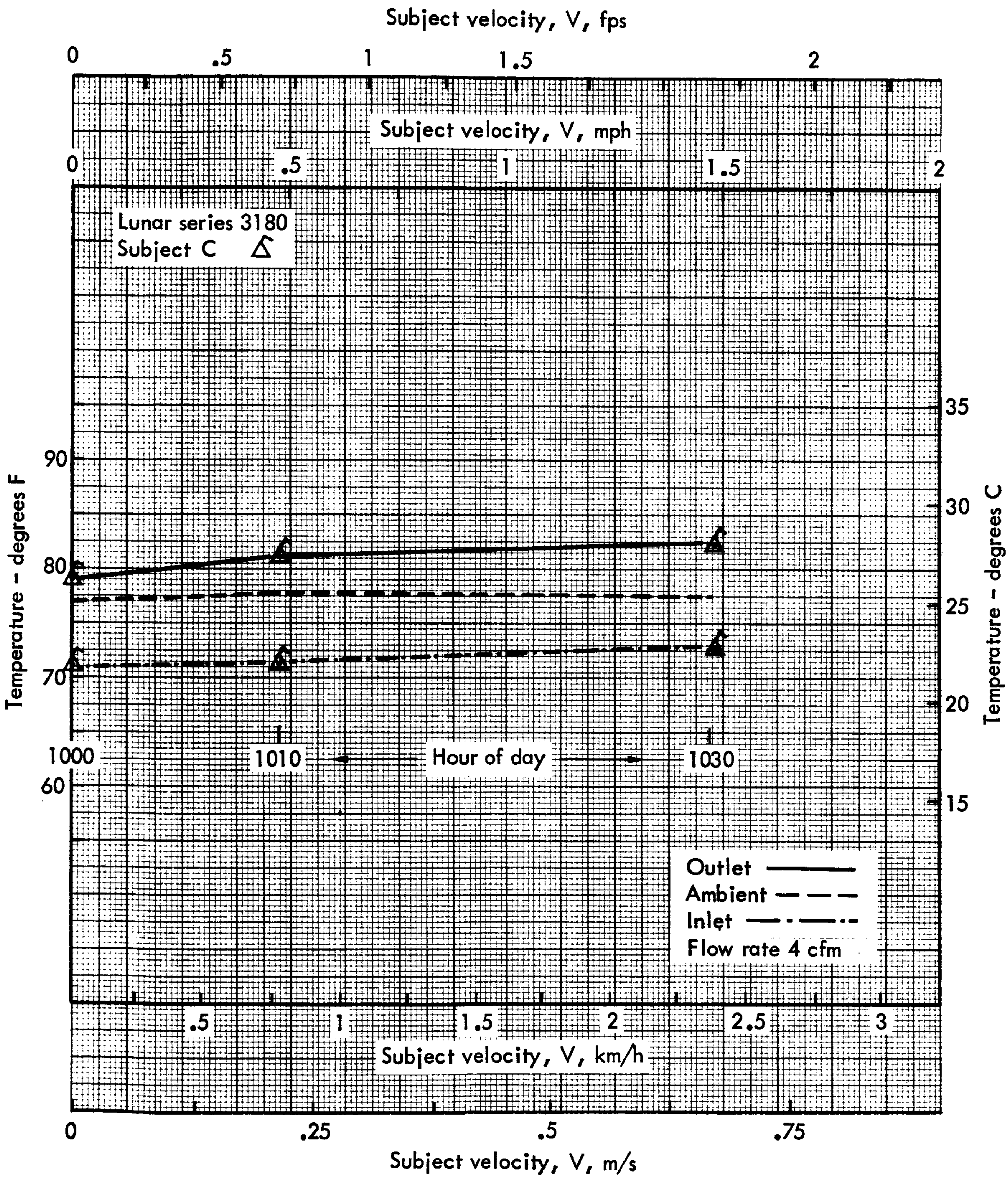


Figure 222. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity stair stepping.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

Test Series 1200

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	loping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	5		4

Respiration, respiratory rate	Figure 223
respiratory volume expired	Figure 224
Metabolism, metabolic energy expenditure rate	Figure 225
metabolic energy expenditure rate per unit length	Figure 226
oxygen consumption	Figure 227
oxygen consumption per unit length	Figure 228
Cardiovascular function, cardiac rate	Figure 229
Body temperature, mean body temperature	Figure 230
Pressure suit environmental data	Not obtained

Comments:

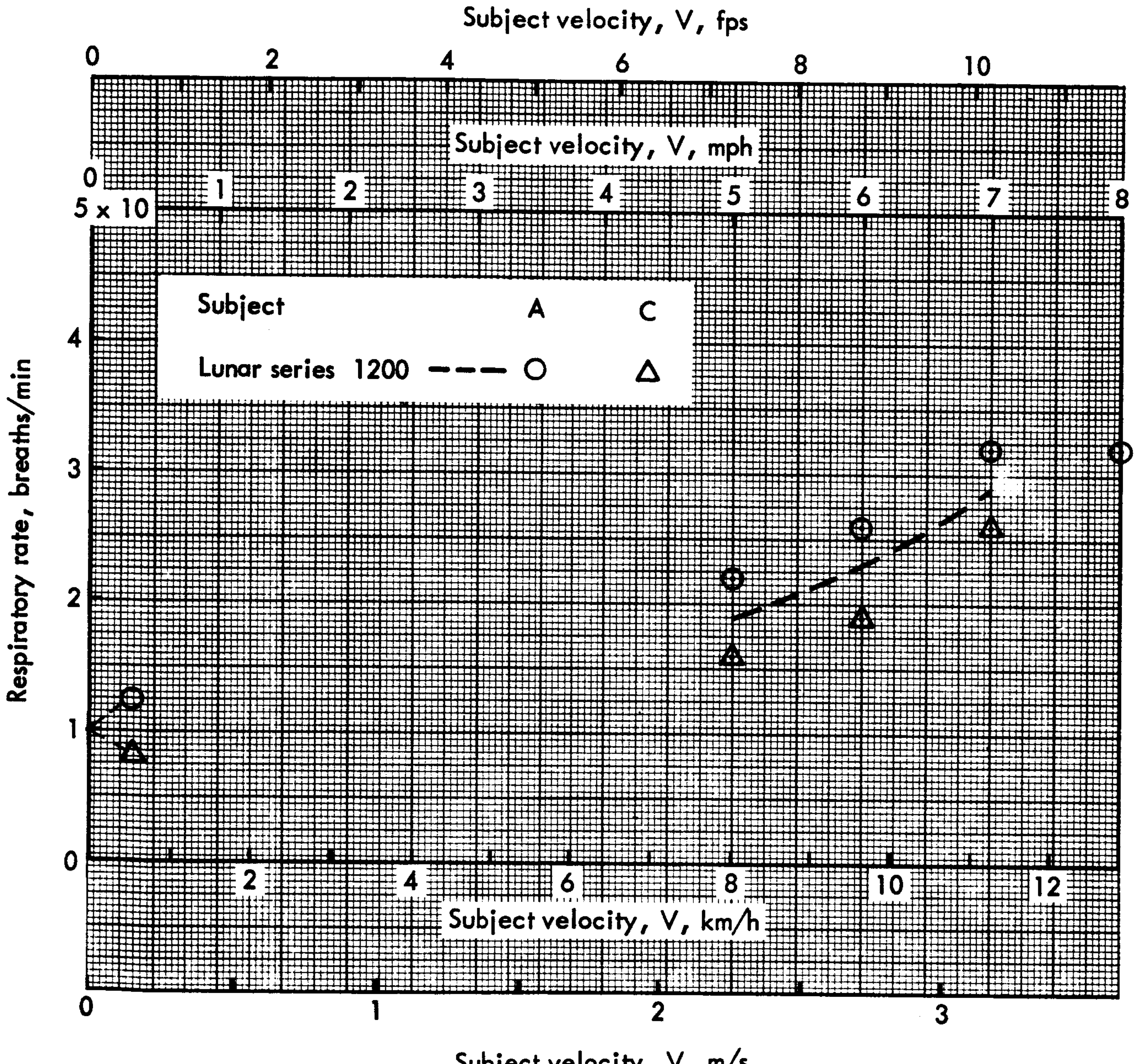


Figure 223. – Average respiratory rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

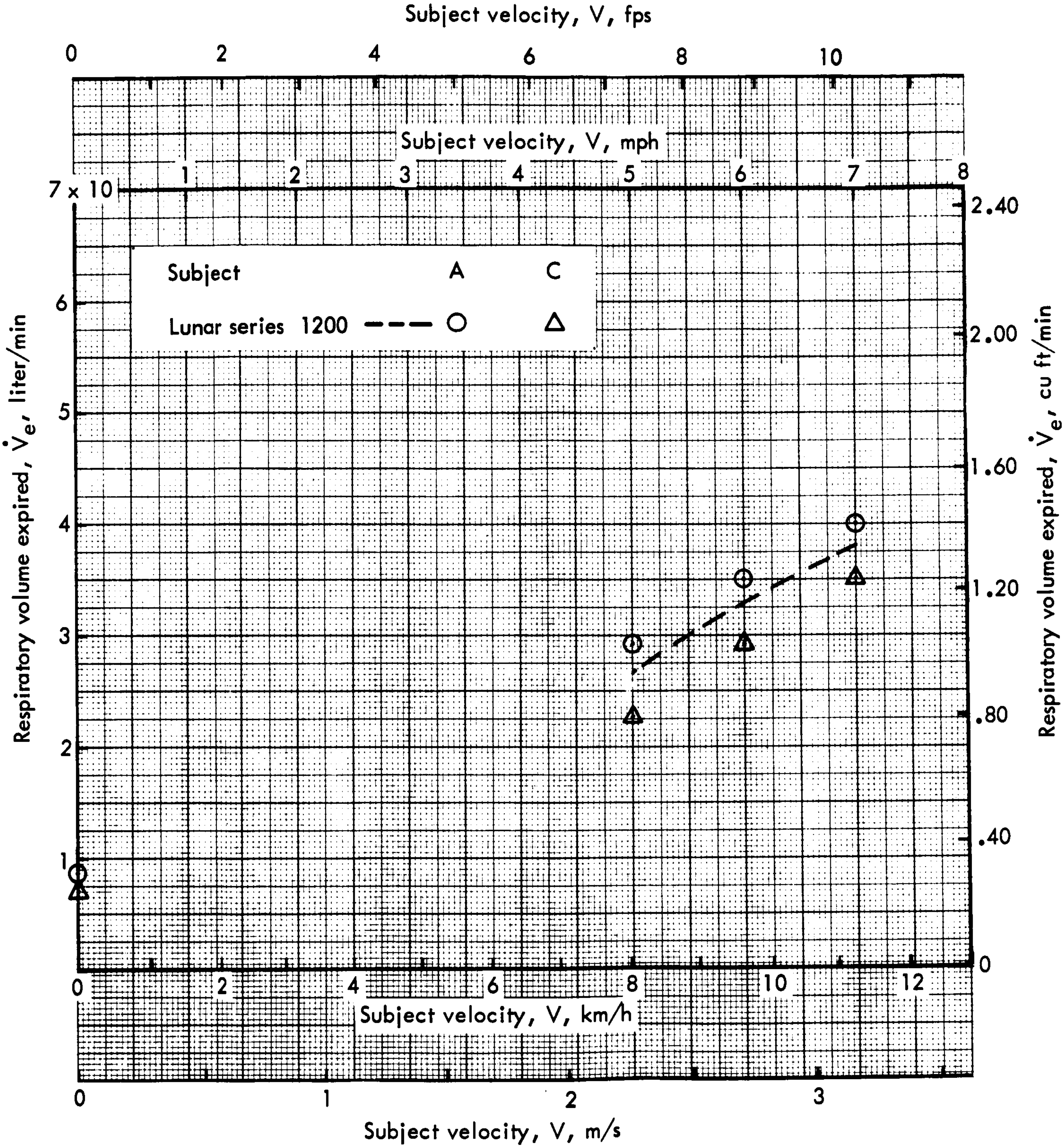


Figure 224. – Average mean respiratory volume versus subject velocity loping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

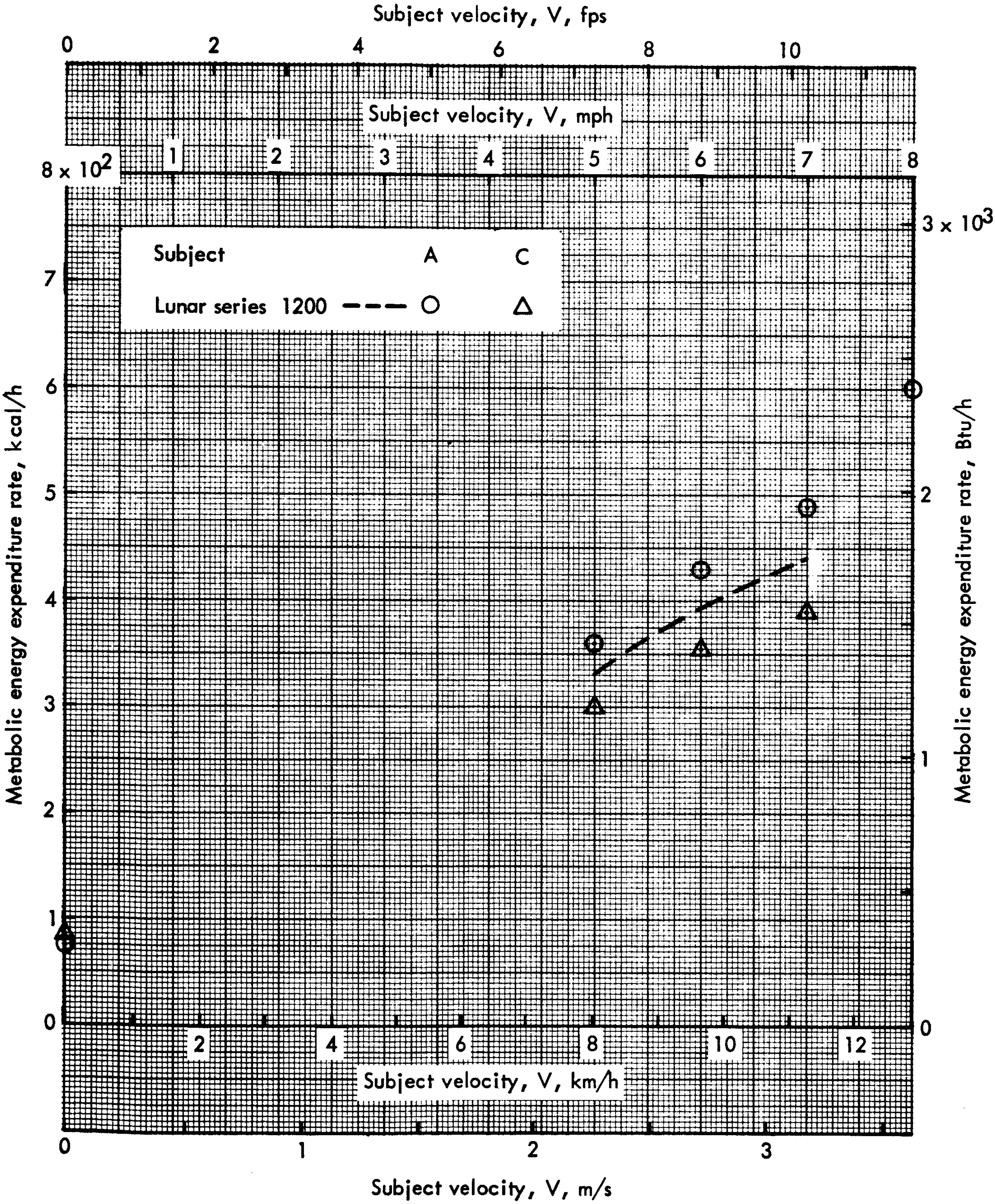


Figure 225. – Average metabolic energy expenditure rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

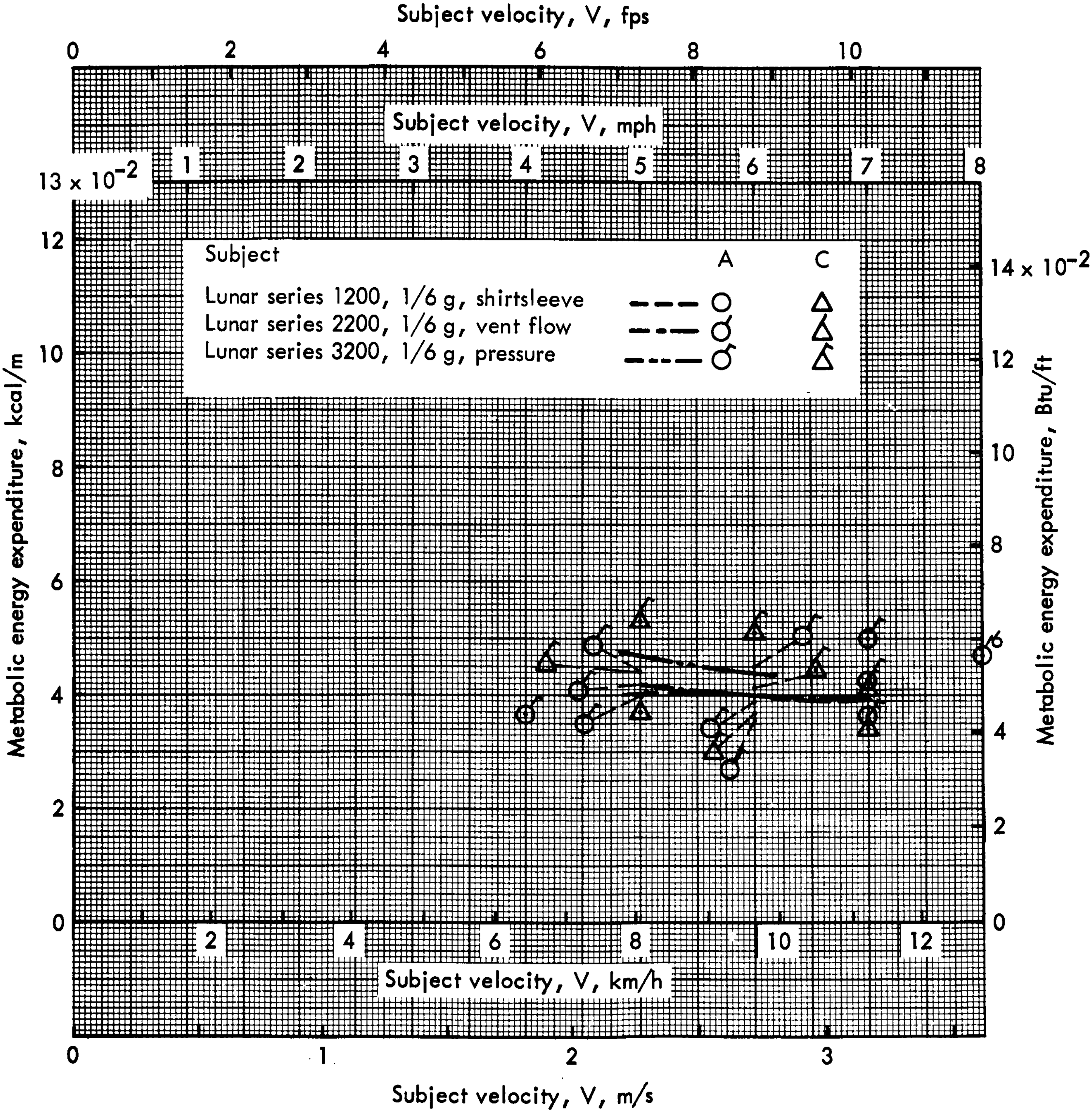


Figure 226. – Average metabolic energy expenditure per unit length versus subject velocity loping horizontally.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

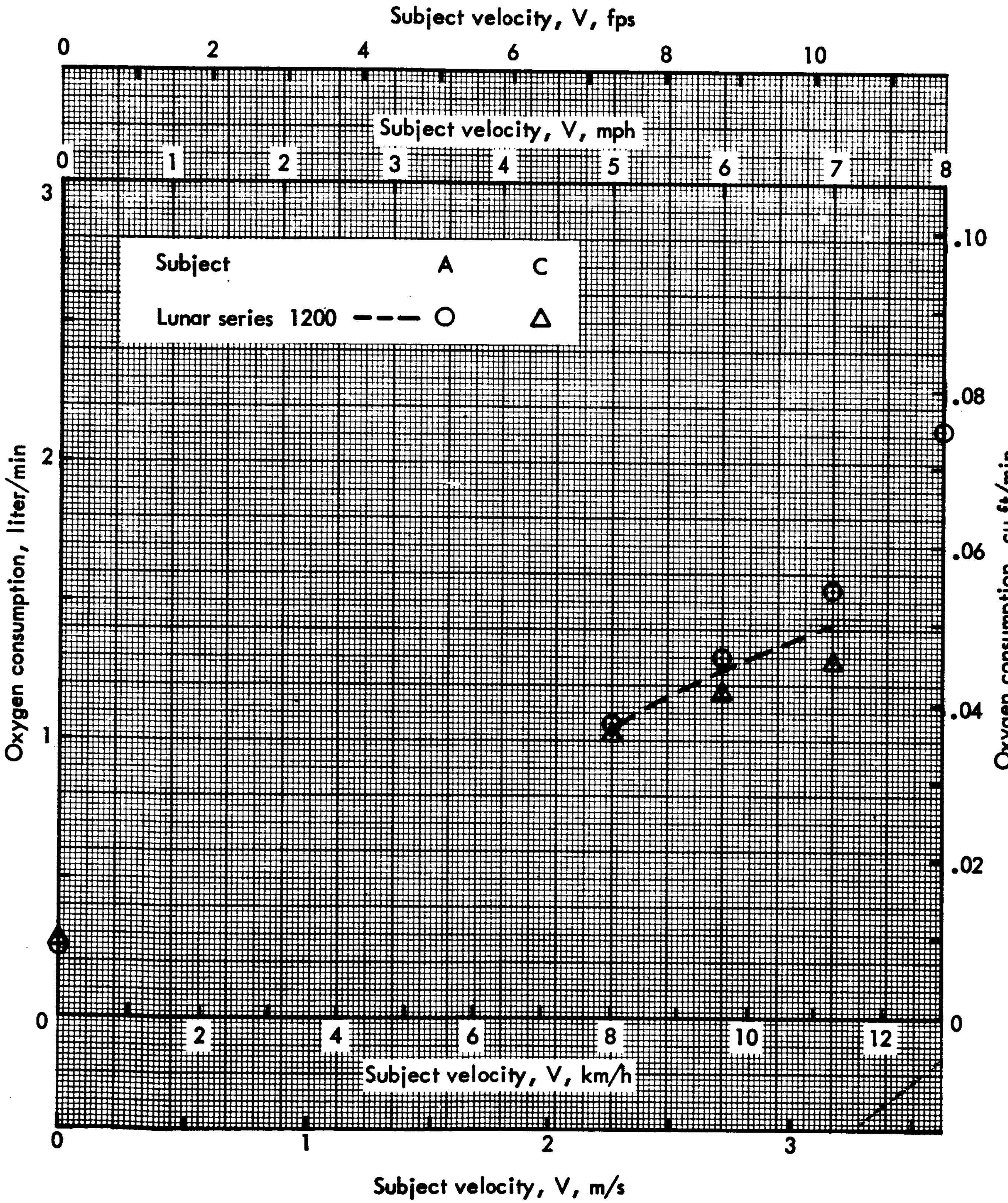


Figure 227. – Average oxygen consumption versus subject velocity loping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

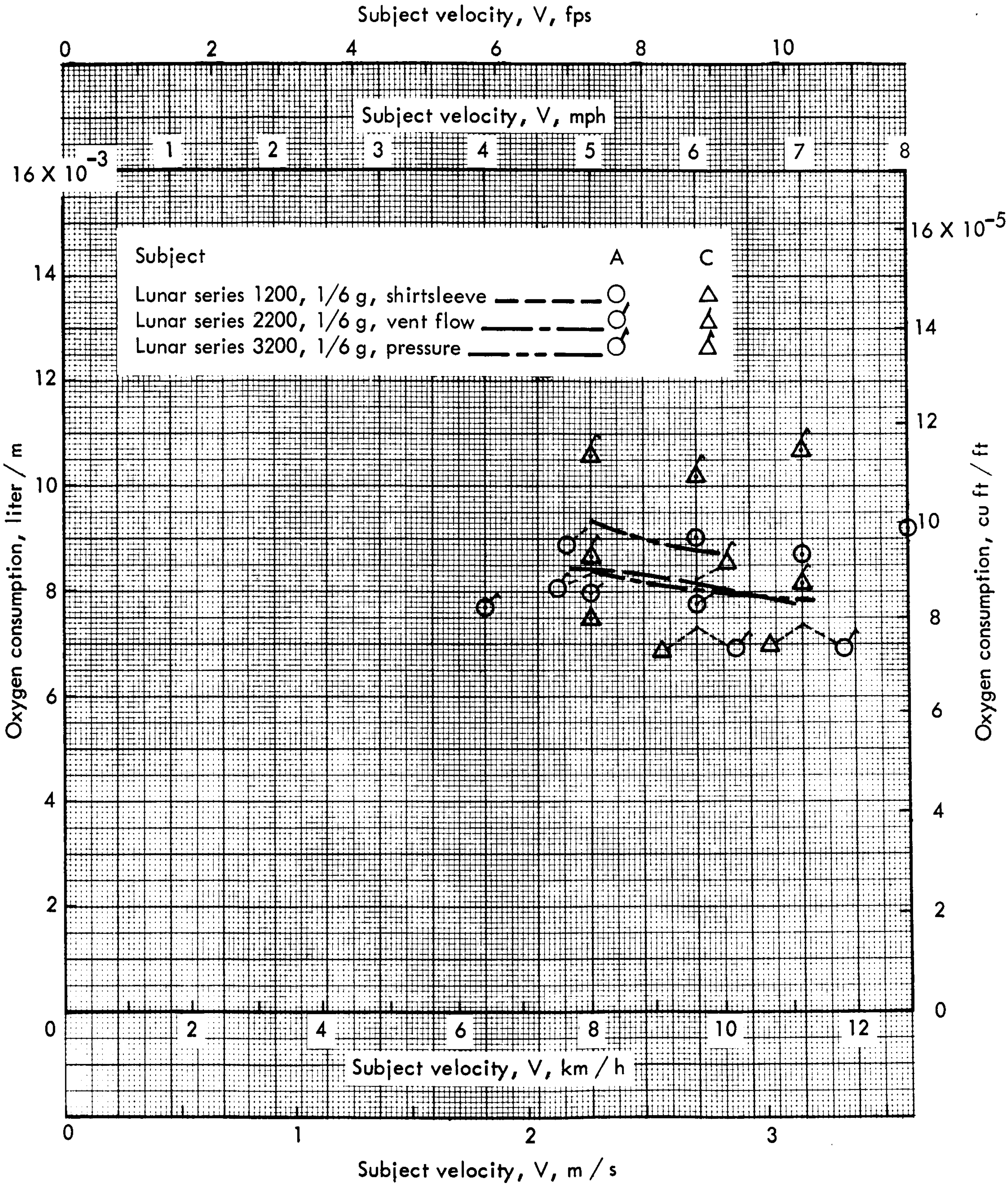


Figure 228. – Average oxygen consumption per unit length versus subject velocity loping horizontally.

Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

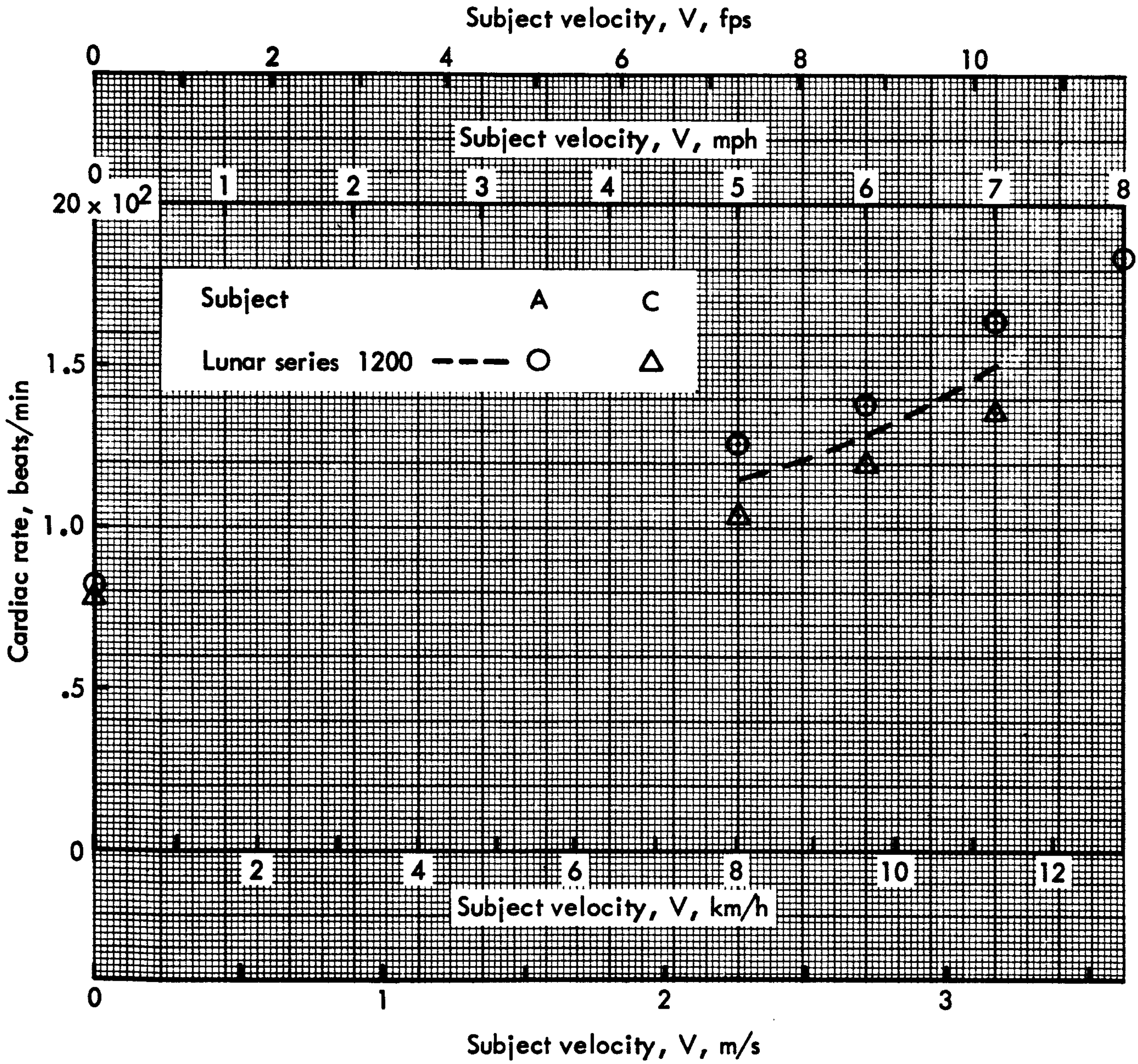


Figure 229. – Average cardiac rate versus subject velocity loping horizontally. Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

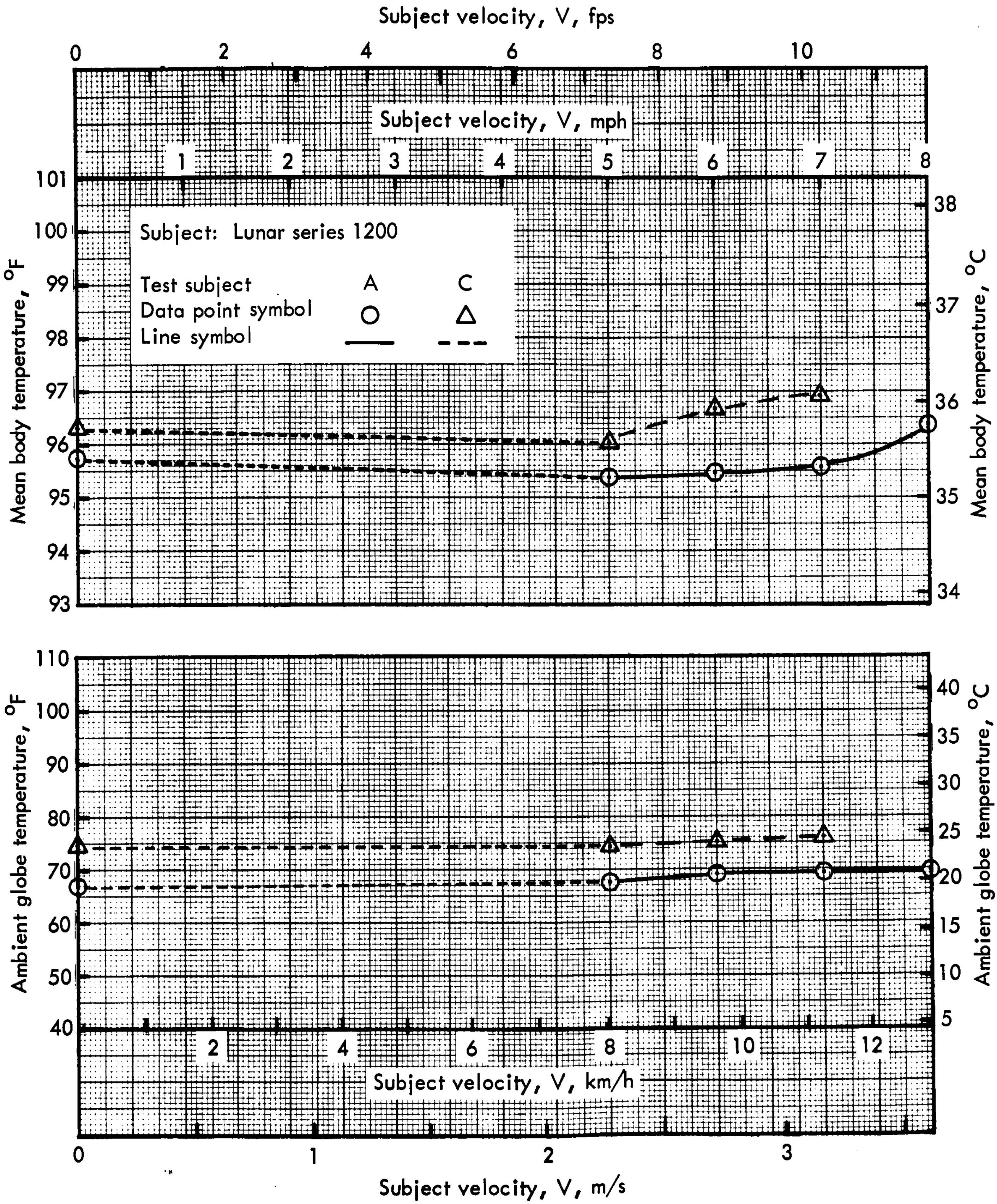


Figure 230. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity loping horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

Test Series 2200

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	x
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	
Work Activity	loping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	4		4

Respiration, respiratory rate	Figure 231
respiratory volume expired	Figure 232
Metabolism, metabolic energy expenditure rate	Figure 233
metabolic energy expenditure rate per unit length	Figure 226
oxygen consumption	Figure 234
oxygen consumption per unit length	Figure 228
Cardiovascular function, cardiac rate	Figure 235
Body temperature, mean body temperature	Figure 236
Pressure suit environmental data	Figure 237

Comments:

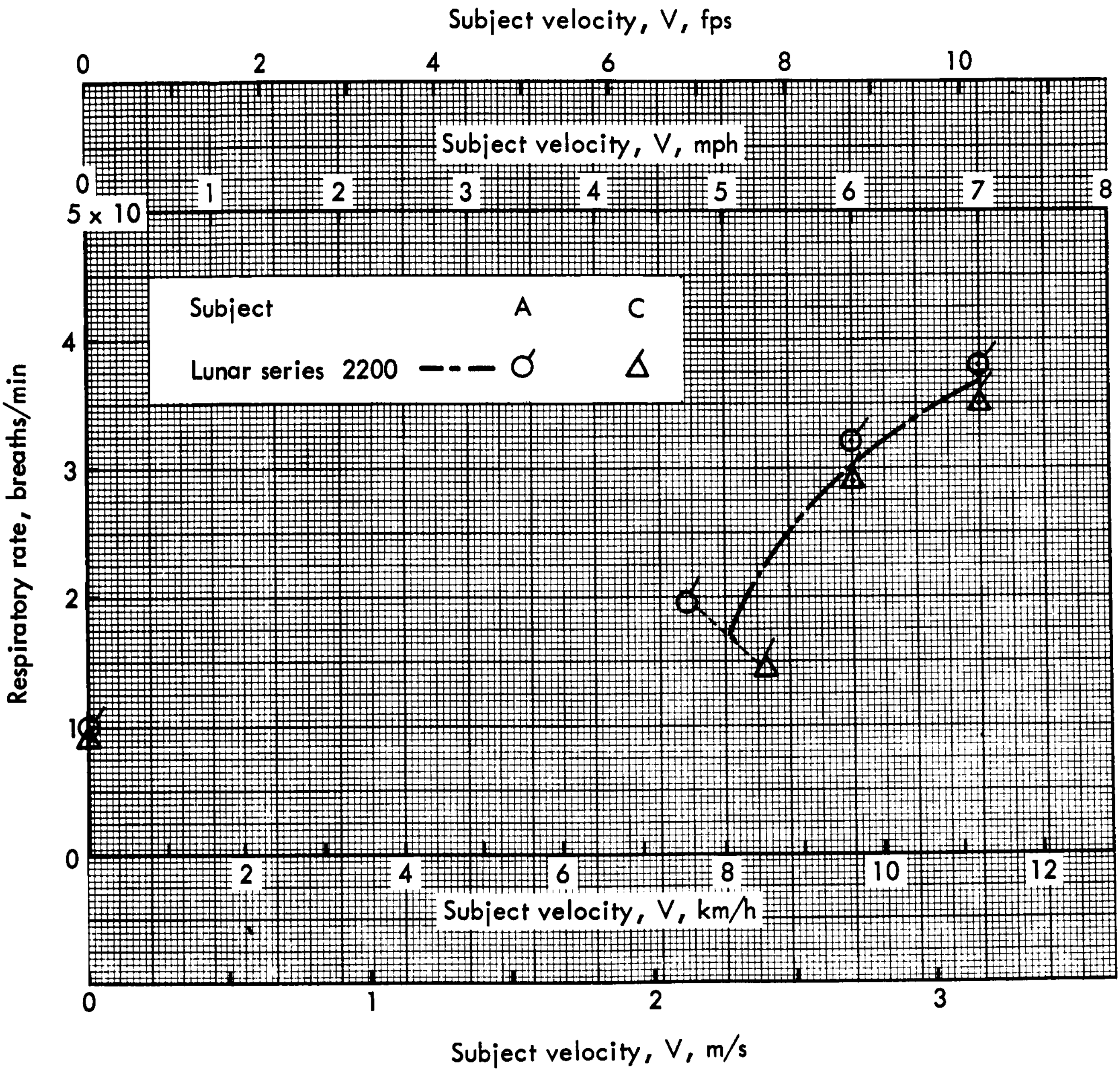


Figure 231. – Average respiratory rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

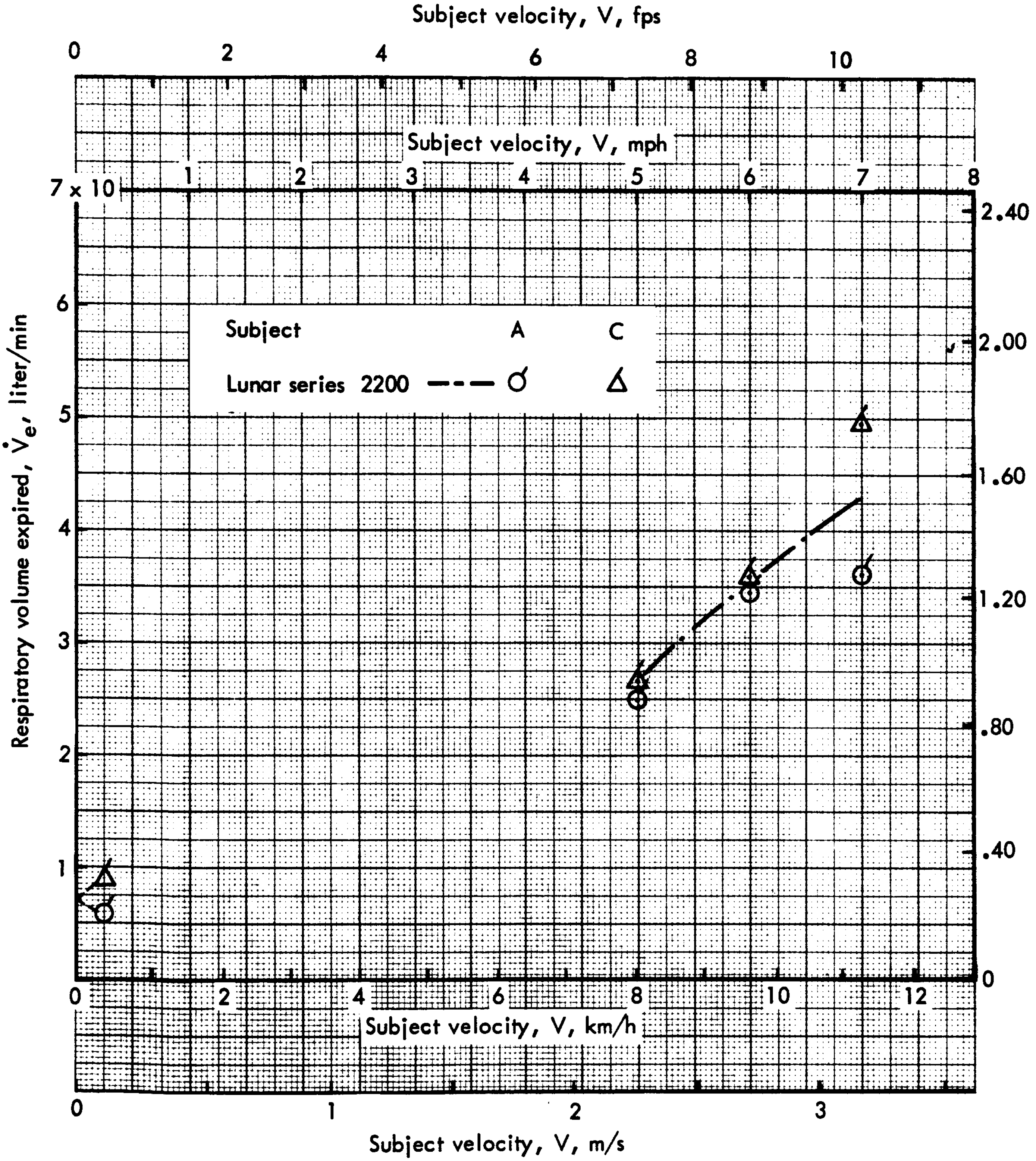


Figure 232. – Average mean respiratory volume versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

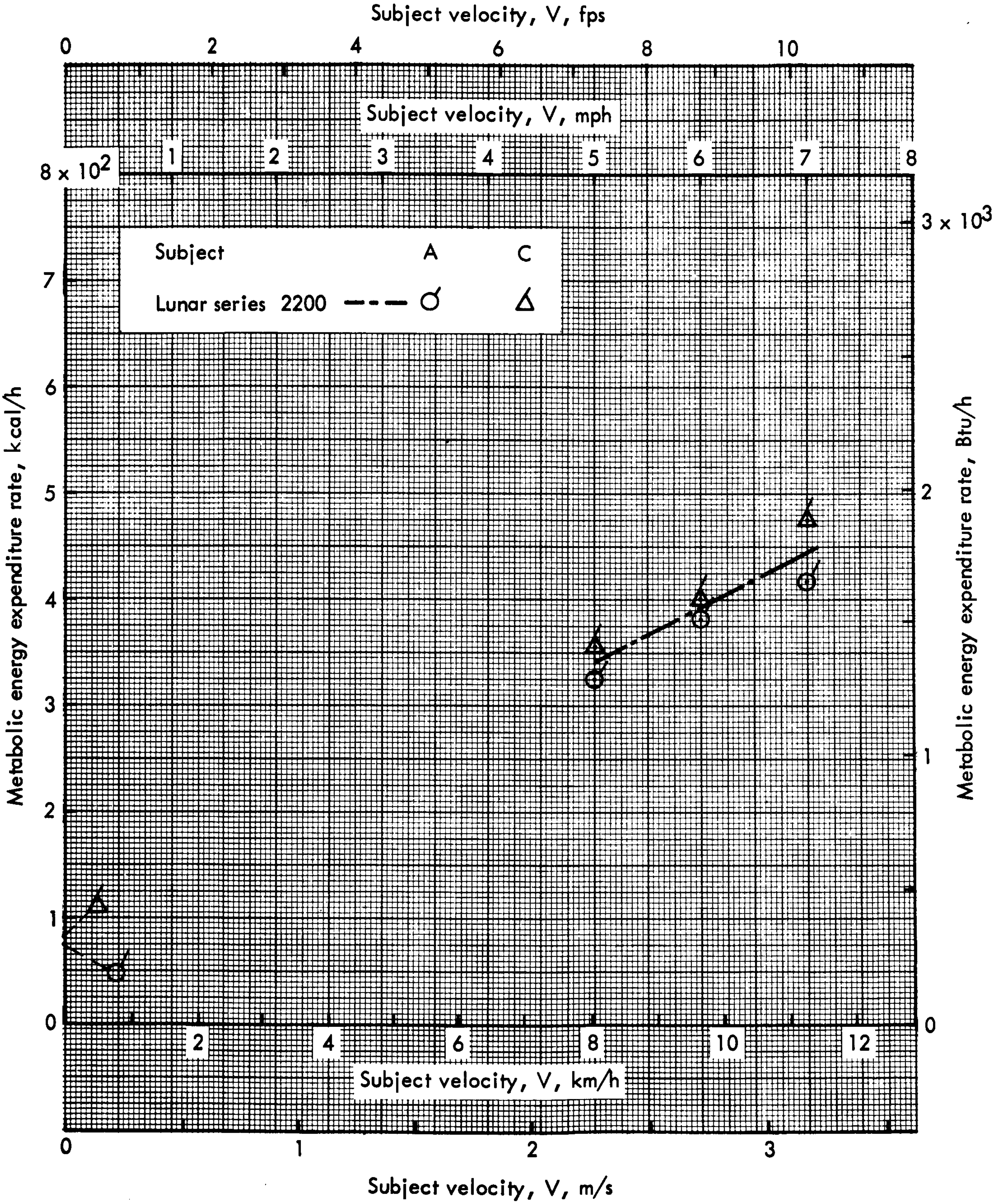


Figure 233. – Average metabolic energy expenditure rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

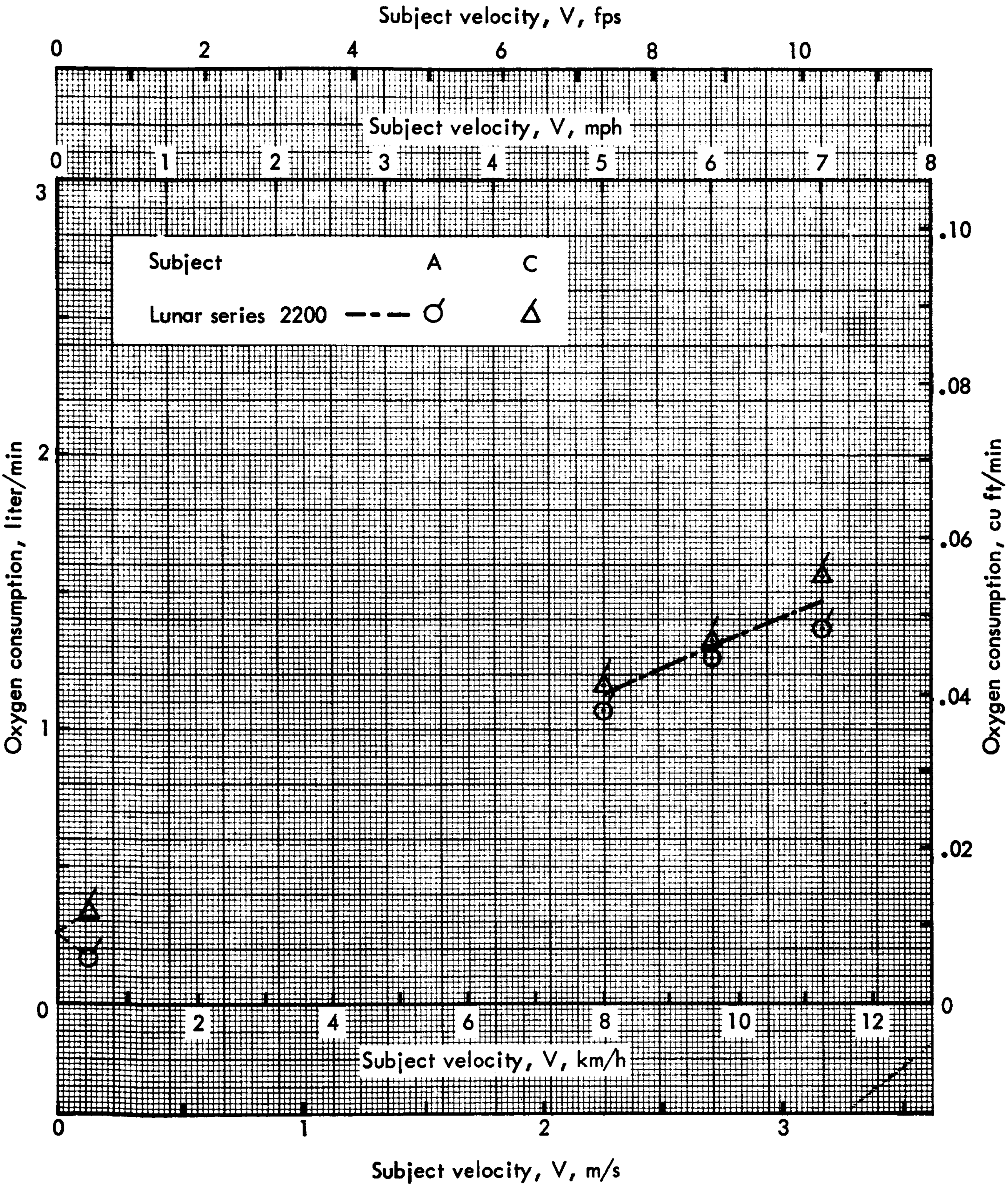


Figure 234. – Average oxygen consumption versus subject velocity loping horizontally

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

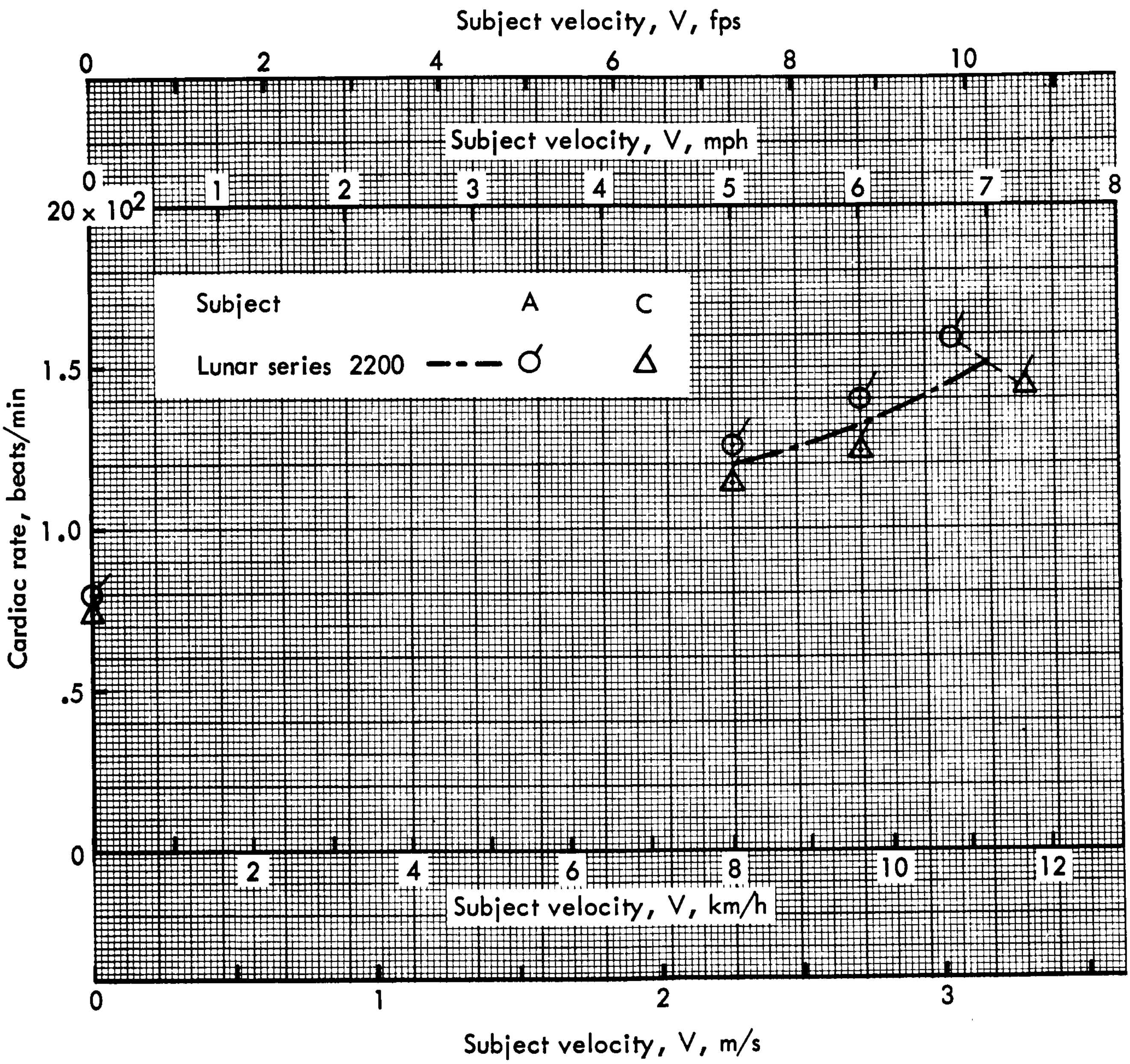


Figure 235. – Average cardiac rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

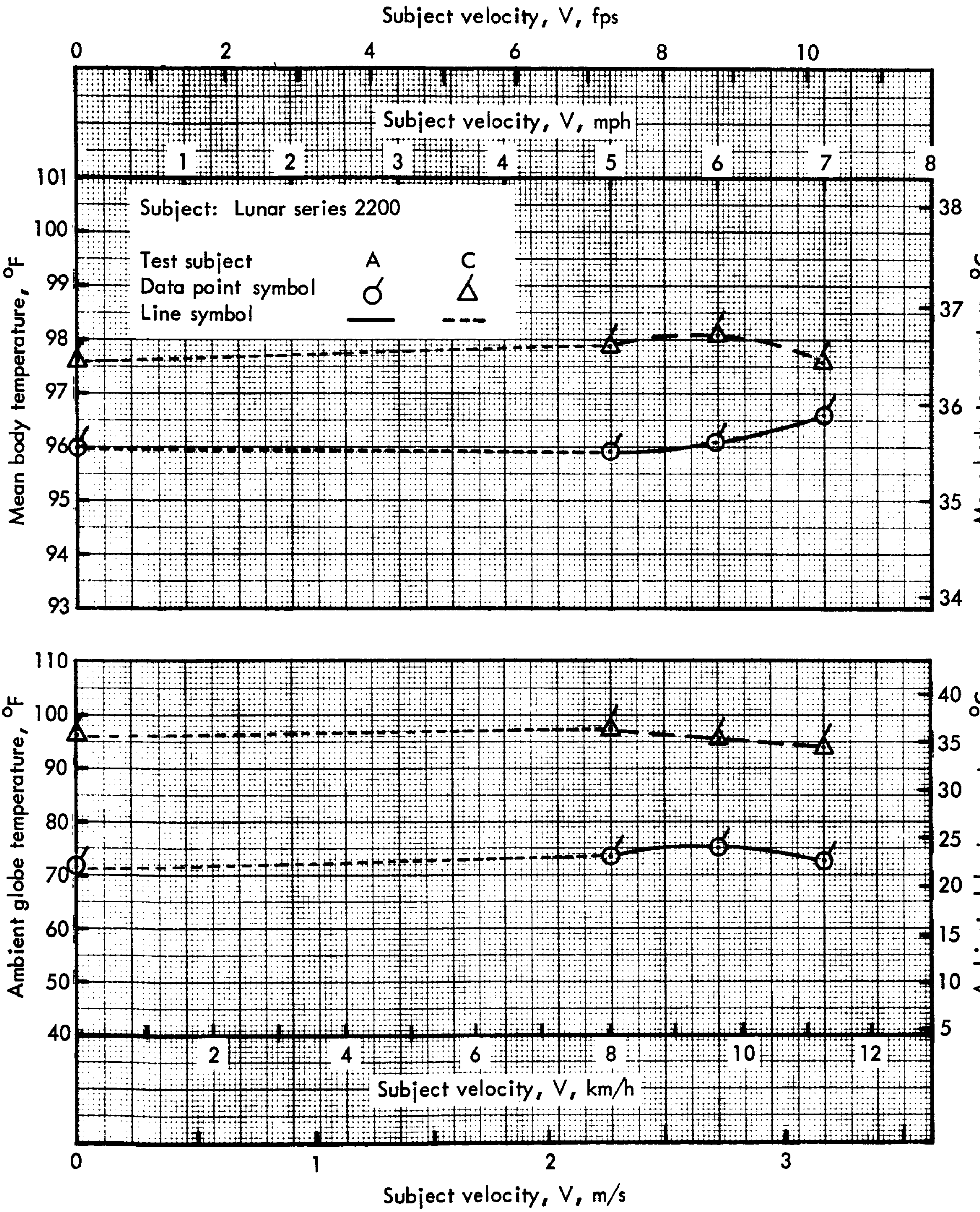


Figure 236. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

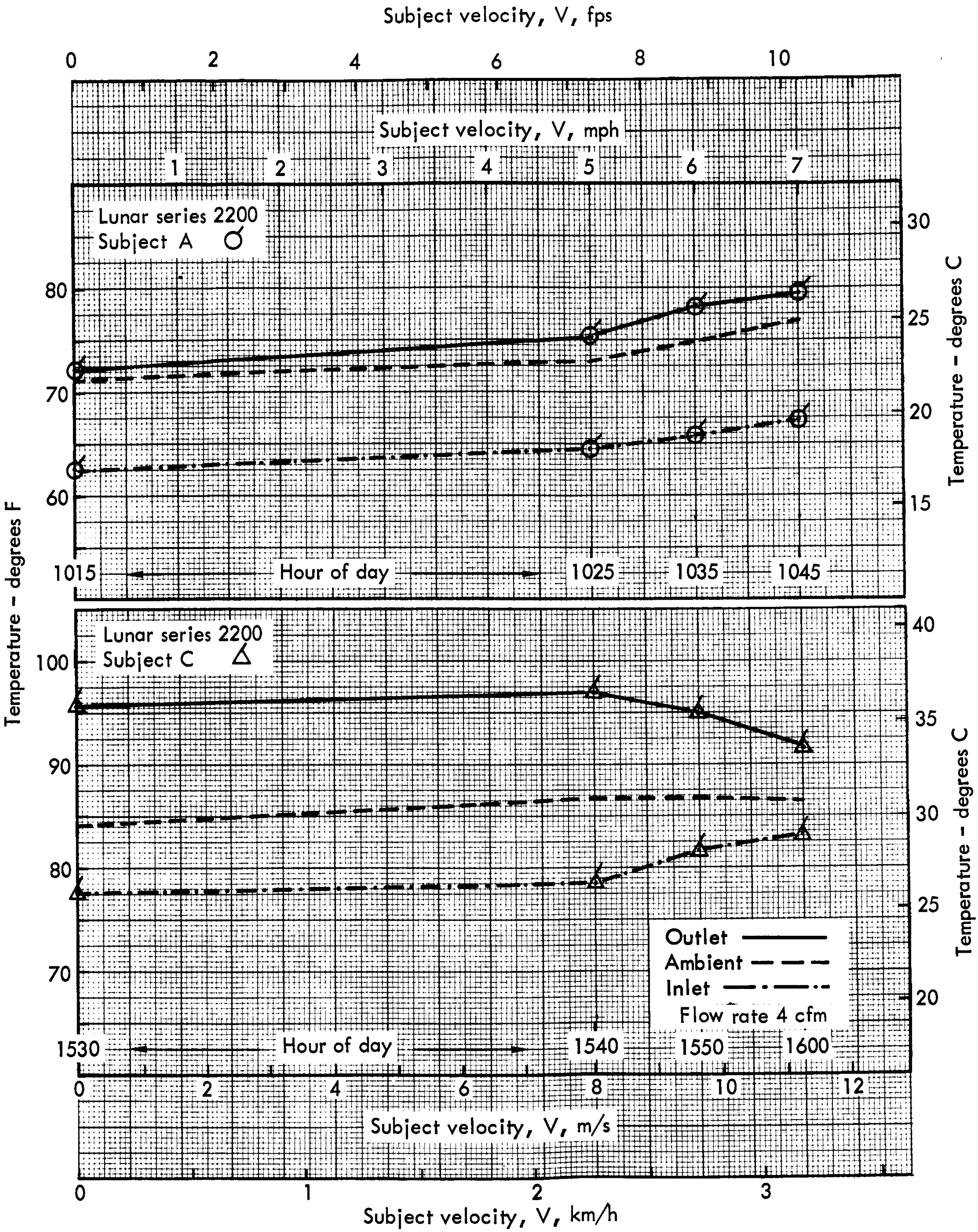


Figure 237. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-vent flow, susp. gear, pack II

Test Series 3200

Test Conditions:

Shirtsleeve		Pressure suit in vent flow	
		Pressure suit at 3.5 psig	x
Instrument Pack I		Instrument Pack II	x
Work Activity	loping	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		x
Number of Tests	5		5

Respiration,	respiratory rate	Figure 238
	respiratory volume expired	Figure 239*
Metabolism,	metabolic energy expenditure rate	Figure 240
	metabolic energy expenditure rate per unit length	Figure 226
	oxygen consumption	Figure 241
	oxygen consumption per unit length	Figure 228
Cardiovascular function,	cardiac rate	Figure 242
Body temperature,	mean body temperature	Figure 243
Pressure suit environmental data		Figure 244

Comments:

* The expired respiratory volume and cardiac rate was low at 7 mph for subject C because this was his first dynamic test performed on a different day.

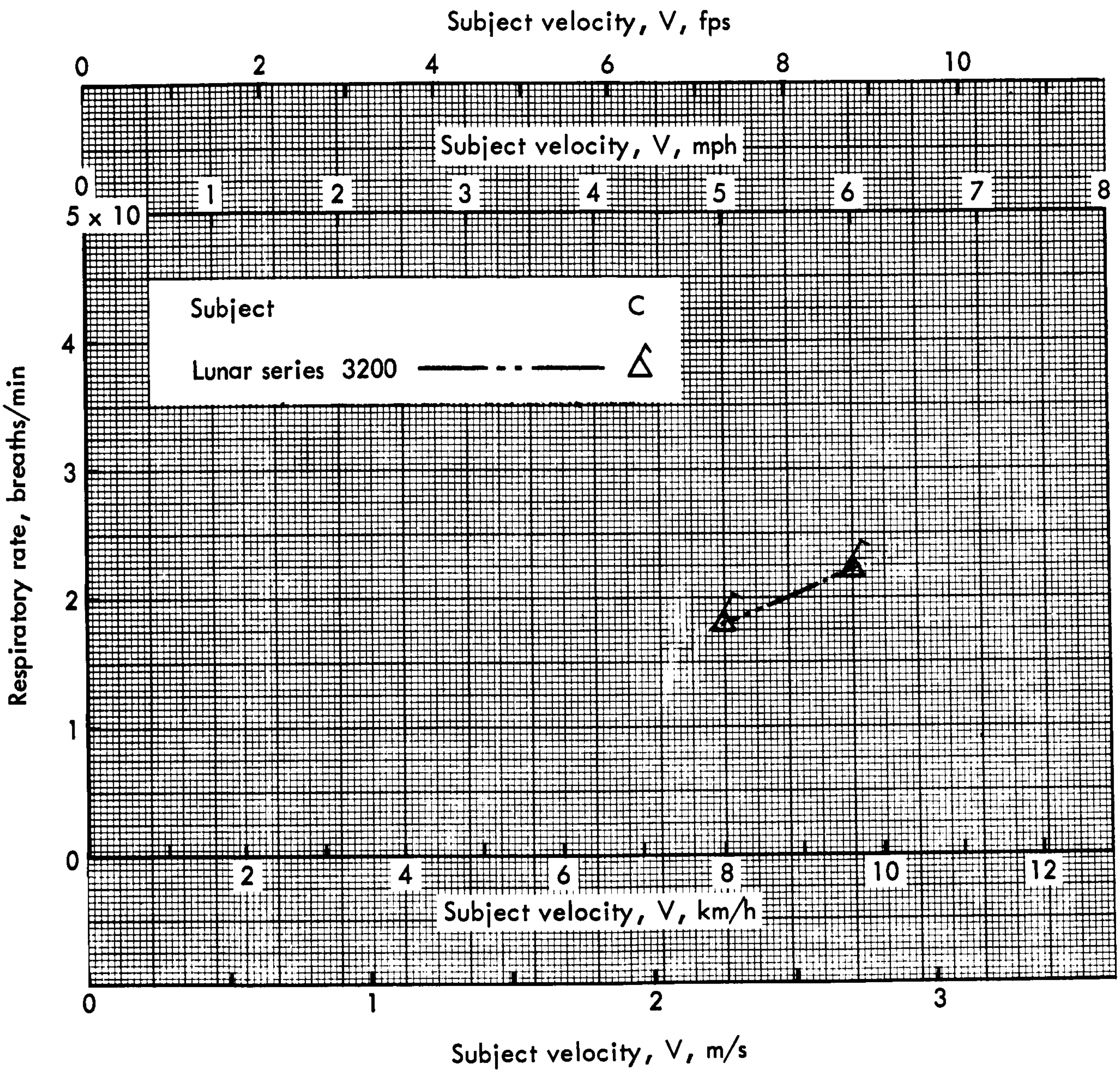


Figure 238. – Respiratory rate versus subject velocity loping horizontally.
Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

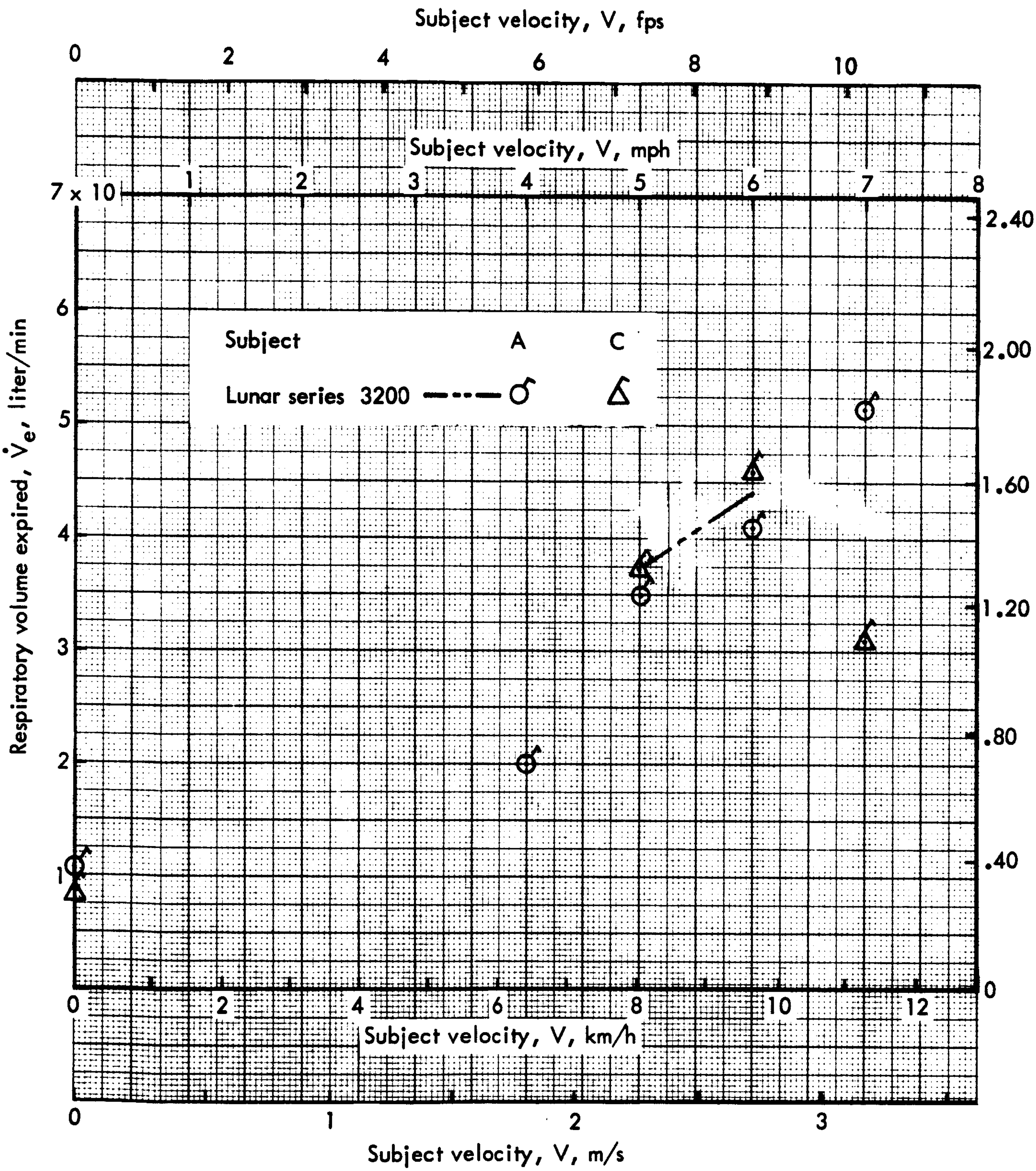


Figure 239. – Average mean respiratory volume versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

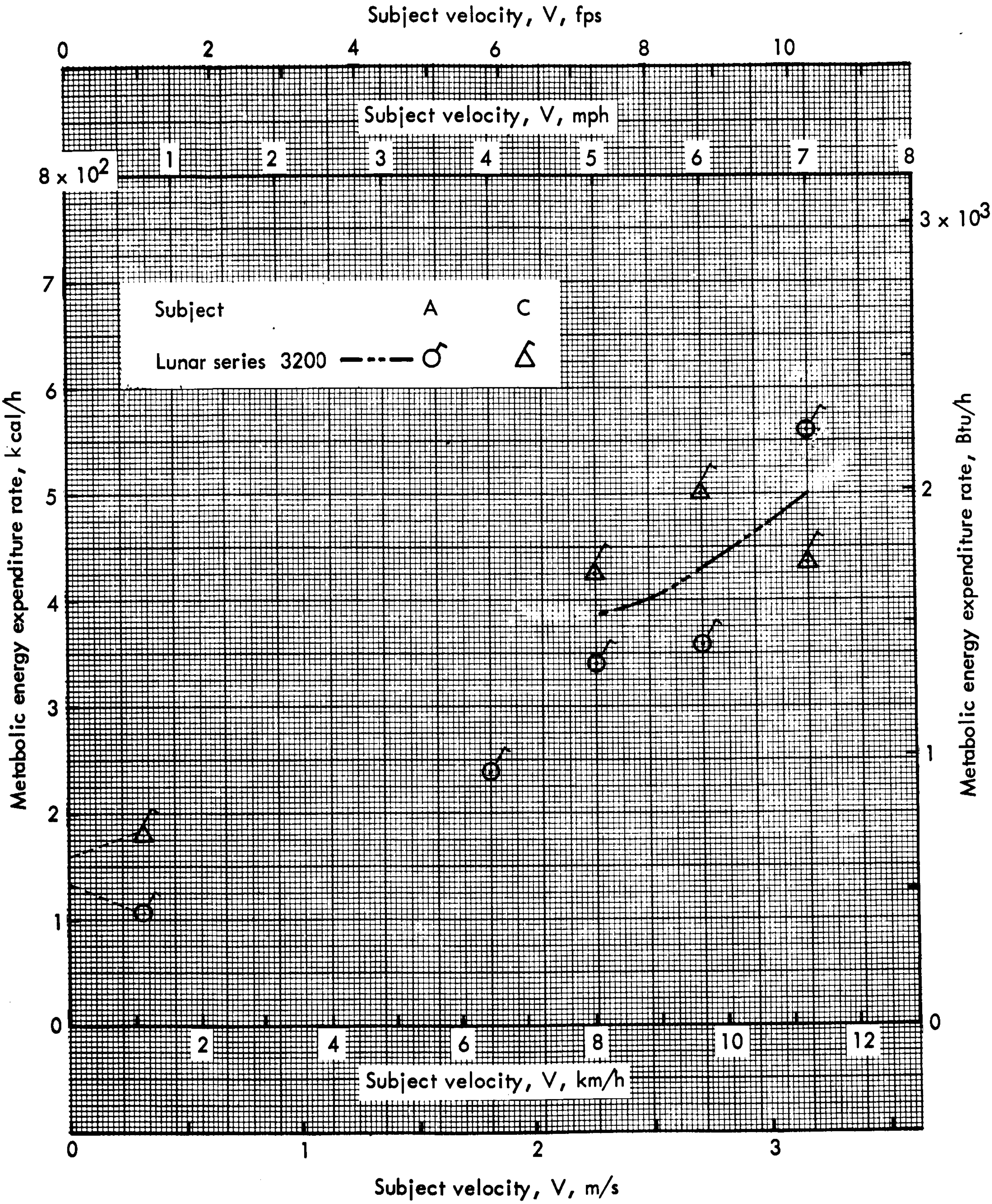


Figure 240. – Average metabolic energy expenditure rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

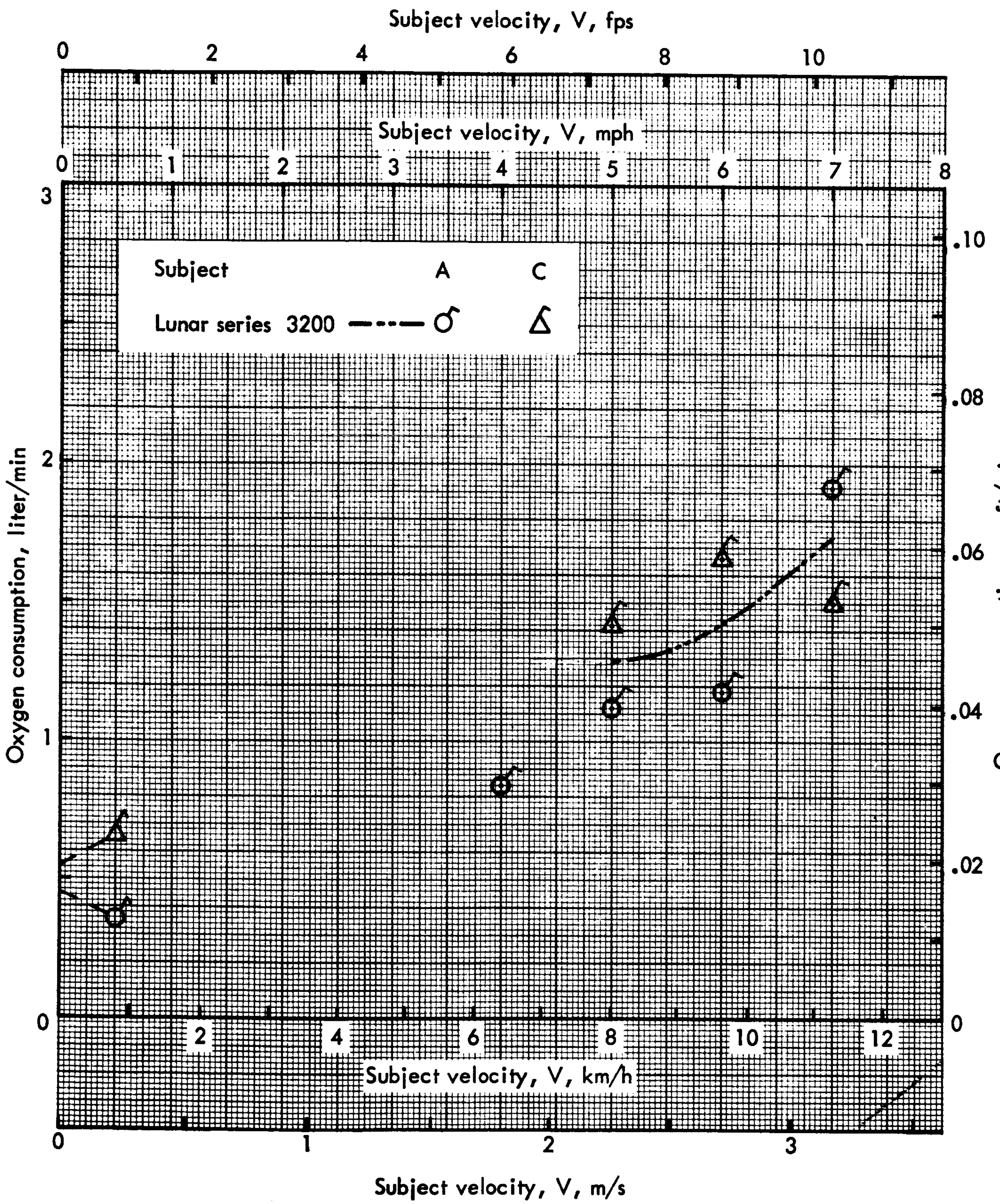


Figure 241. – Average oxygen consumption versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

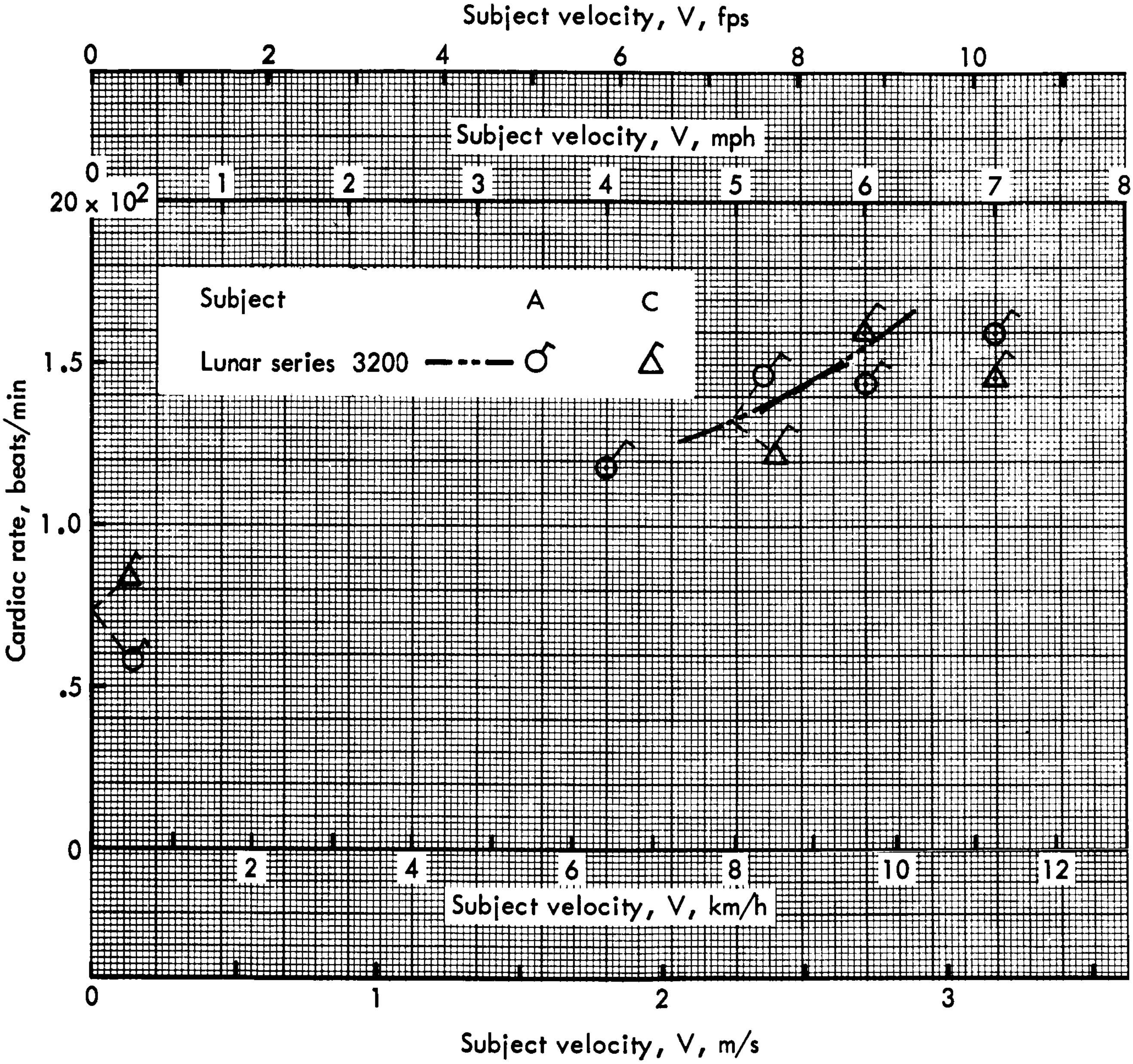


Figure 242. – Average cardiac rate versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

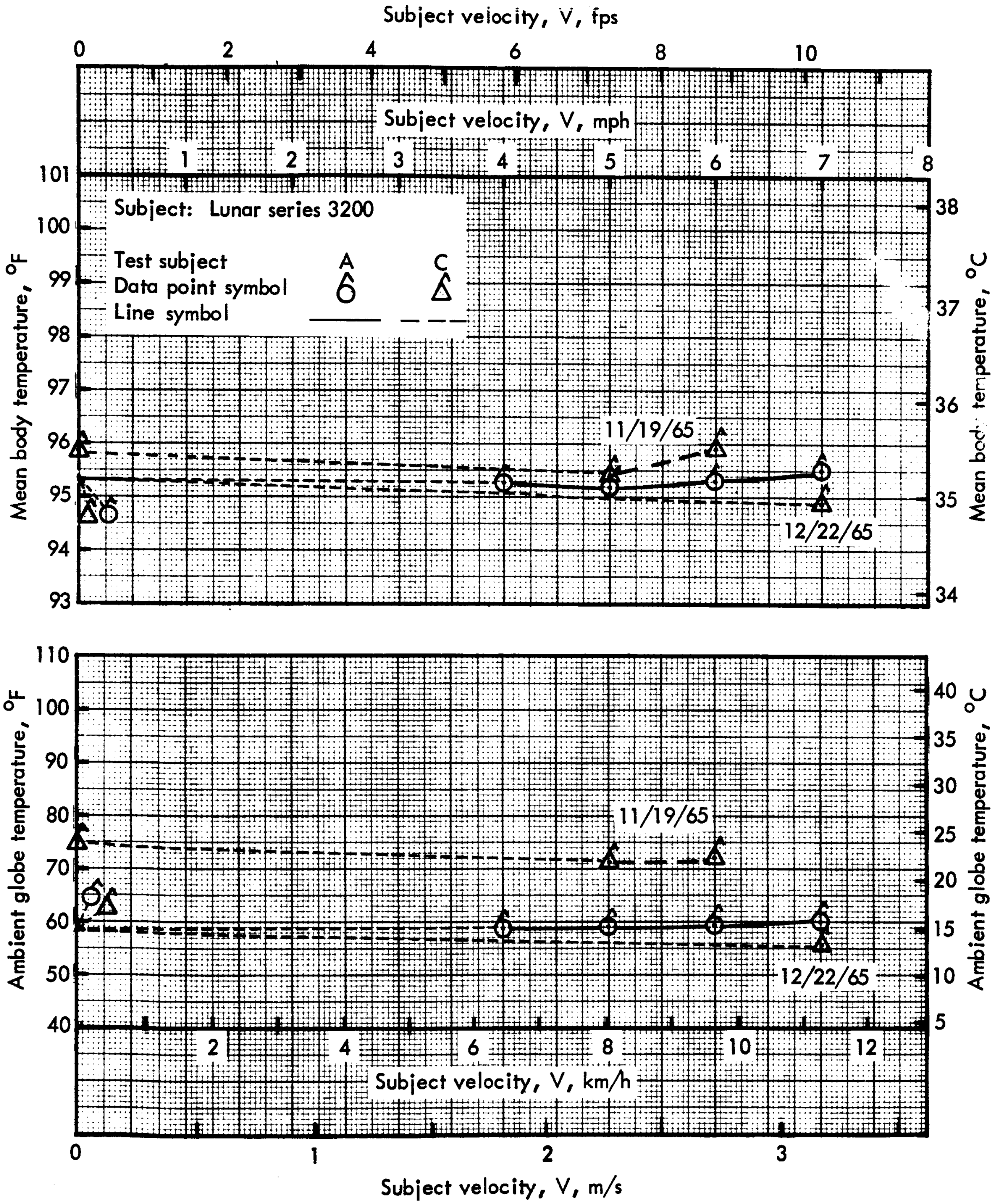


Figure 243. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit-pressurized, susp. gear, pack II

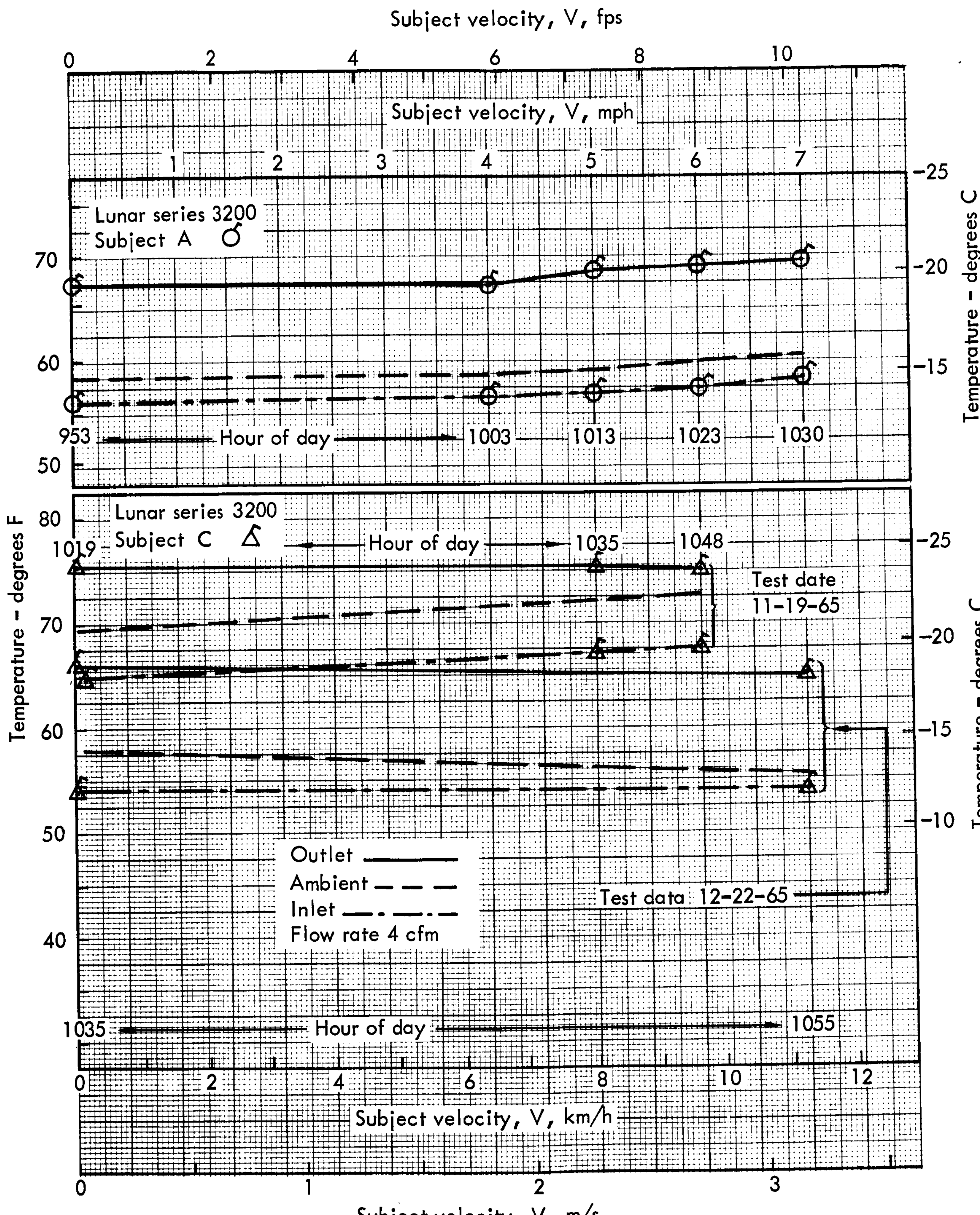


Figure 244. – Ambient (globe thermometer) and pressure suit (inlet and outlet) ventilating air temperatures, versus subject velocity loping horizontally.

Test Conditions: 1/6 g, pressure suit–pressurized, susp. gear, pack II

Test Series 1230

Test Conditions:

Shirtsleeve	x	Pressure suit in vent flow	
		Pressure suit at 3.5 psig	
Instrument Pack I	x	Instrument Pack II	
Work Activity	crawling	Work Variable	horizontally
Gravity: Lunar	x	Earth	

Test Location:

1/6 g Treadmill	x	One g Treadmill	

Test Results:

	A	B	C
Results for Subject	x		
Number of Tests	6		

Respiration, respiratory rate	Figure 245*
respiratory volume expired	Figure 246
Metabolism, metabolic energy expenditure rate	Figure 247
metabolic energy expenditure rate per unit length	Figure 248
oxygen consumption	Figure 249
oxygen consumption per unit length	Figure 250
Cardiovascular function, cardiac rate	Figure 251**
Body temperature, mean body temperature	Figure 252
Pressure suit environmental data	Not obtained

Comments:

* The lower respiratory rate of subject A at 2 mph may be due to the second wind phenomenon.

** Cardiac rate was not obtained at 2.0 and 3.0 mph due to muscle artifacts.

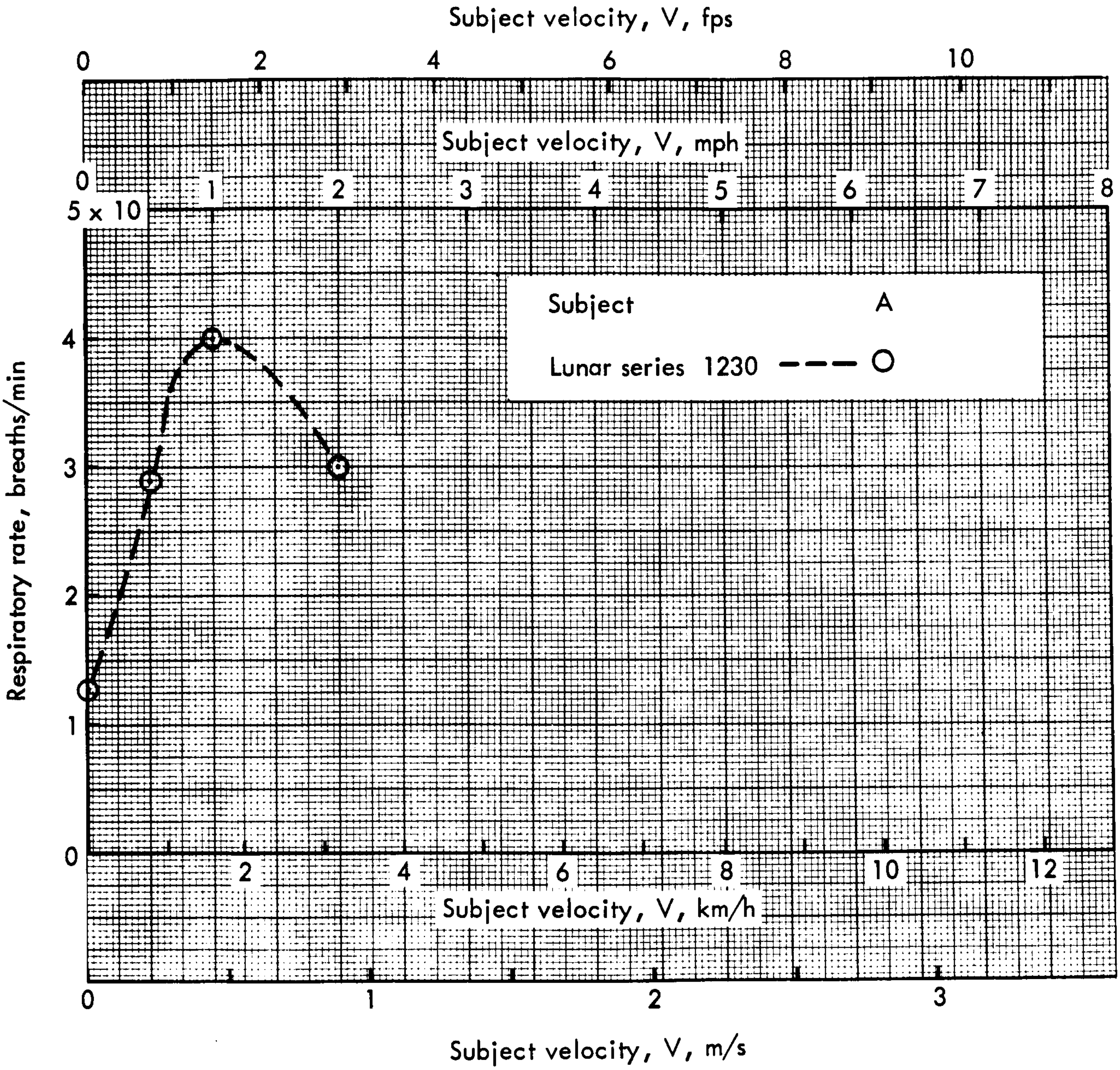


Figure 245. – Respiratory rate versus subject velocity crawling horizontally.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

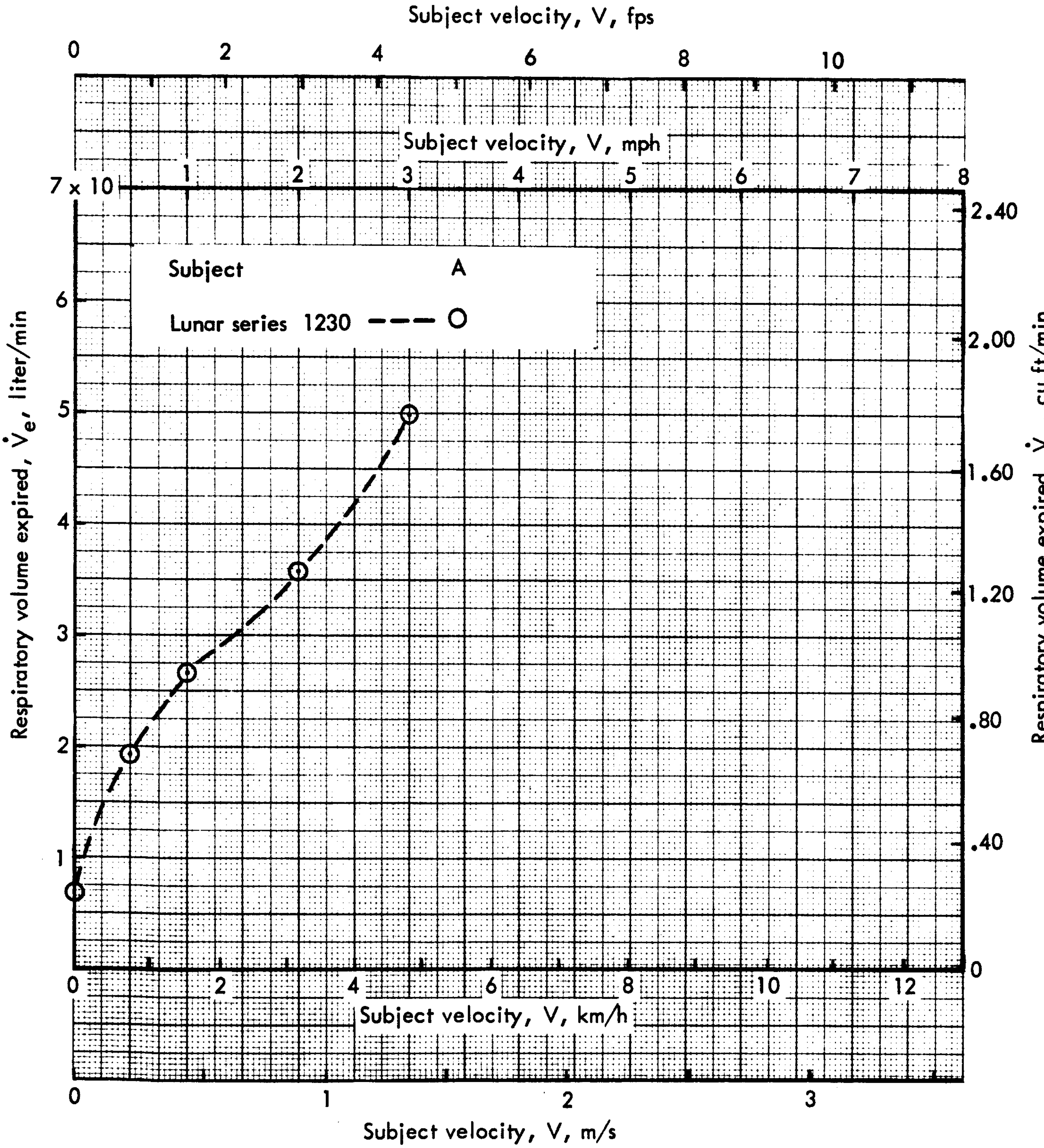


Figure 246. – Average mean respiratory volume versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

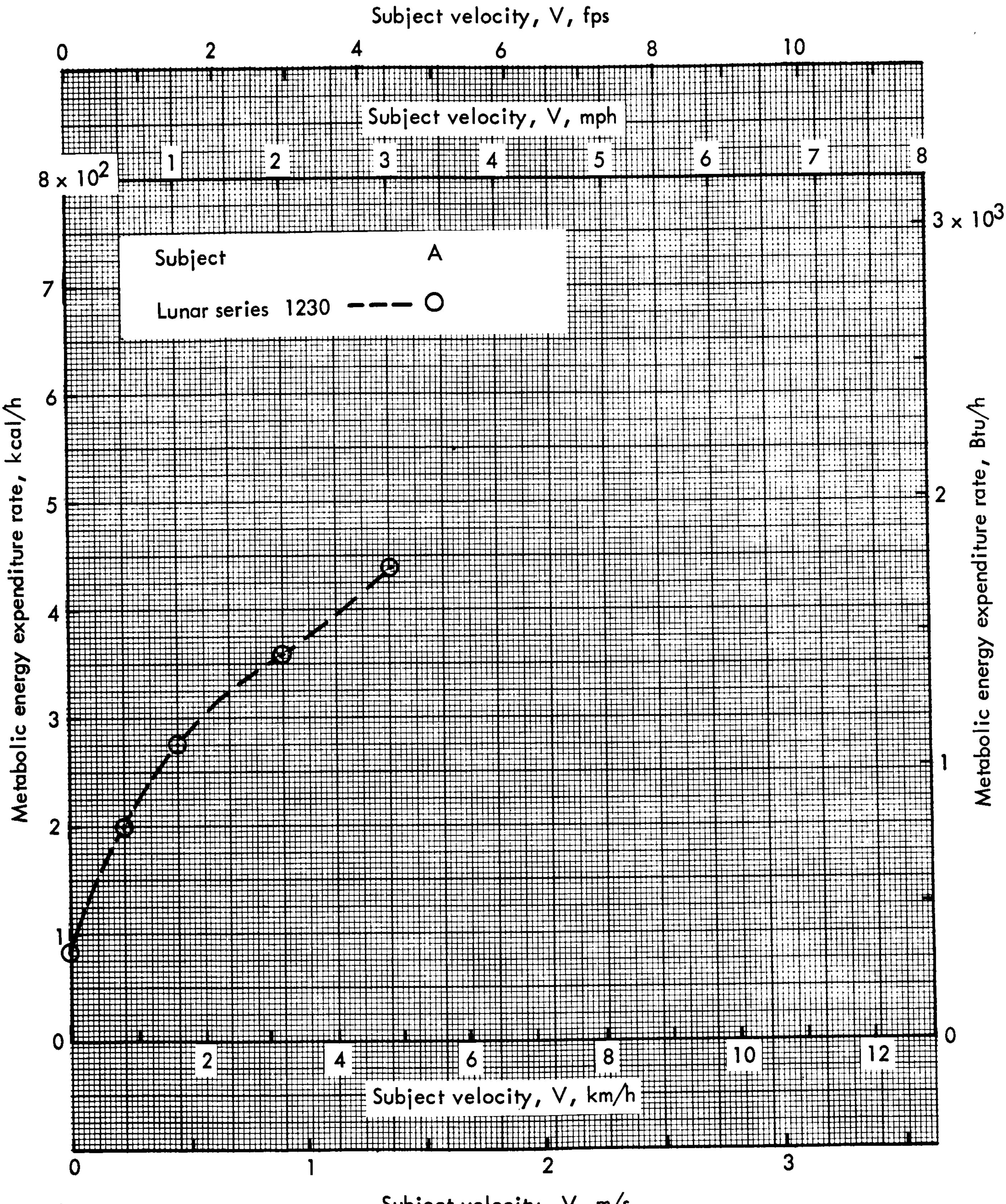


Figure 247. – Average metabolic energy expenditure rate versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

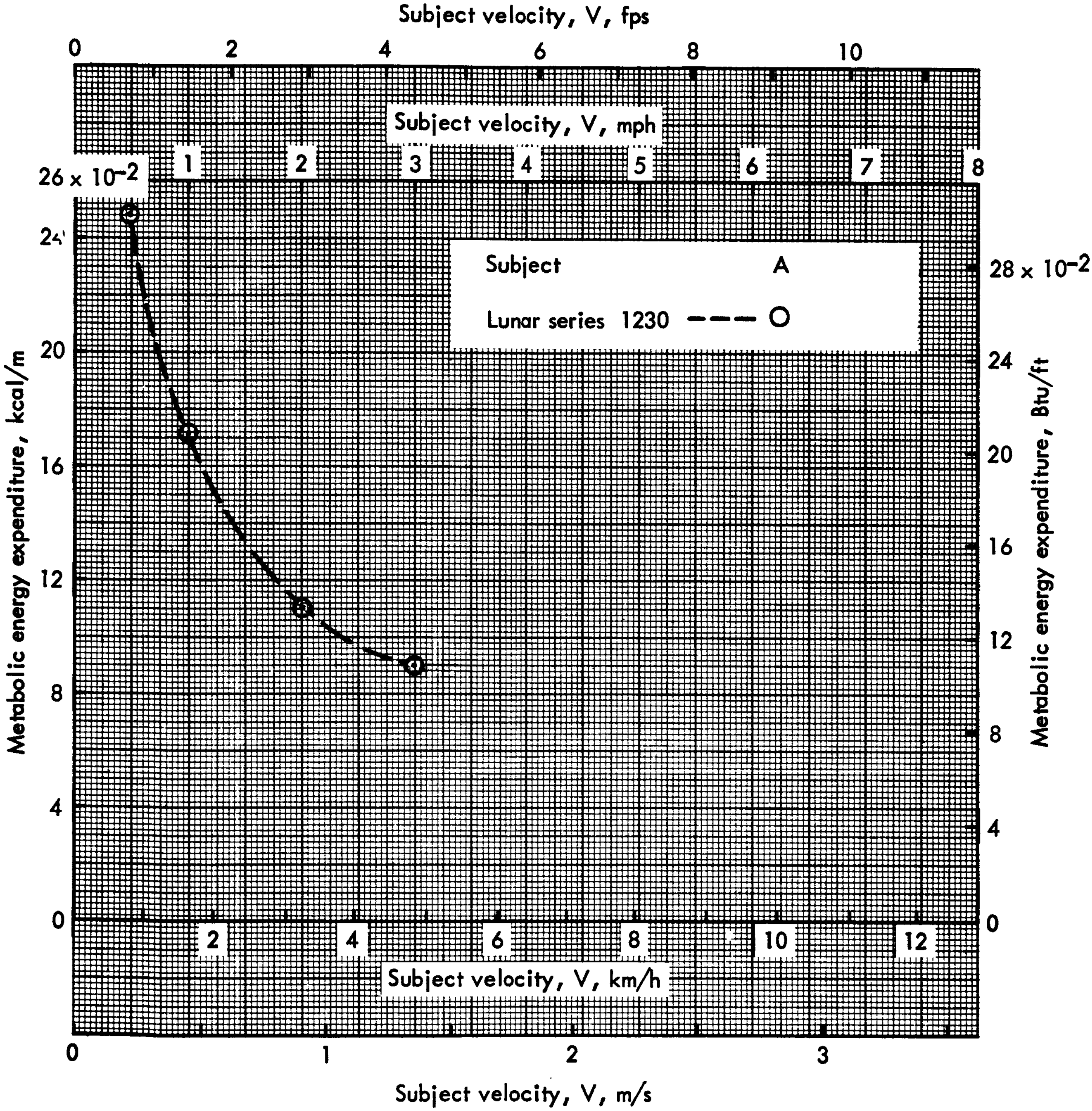


Figure 248. – Metabolic energy expenditure per unit length versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

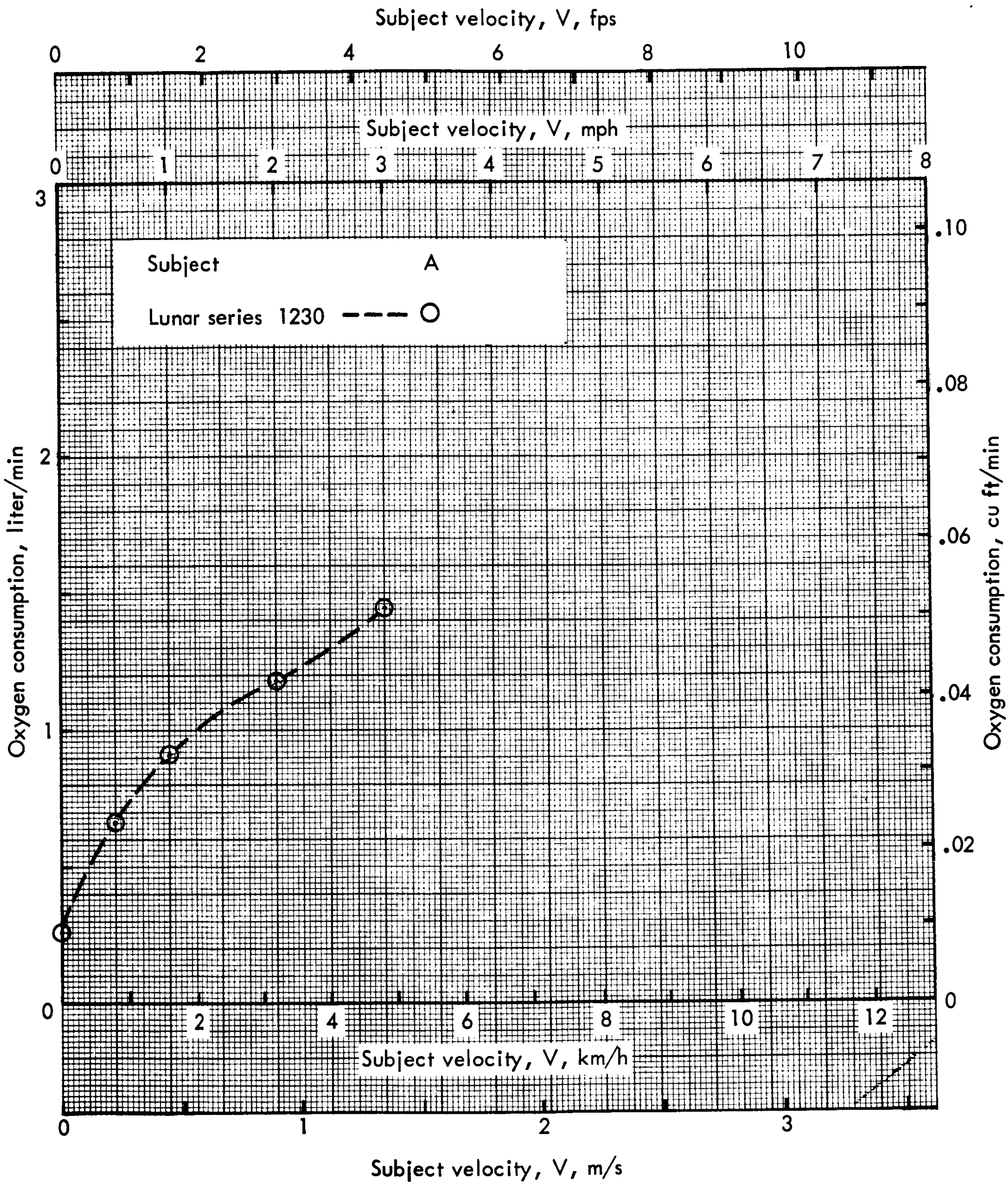


Figure 249. – Oxygen consumption versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

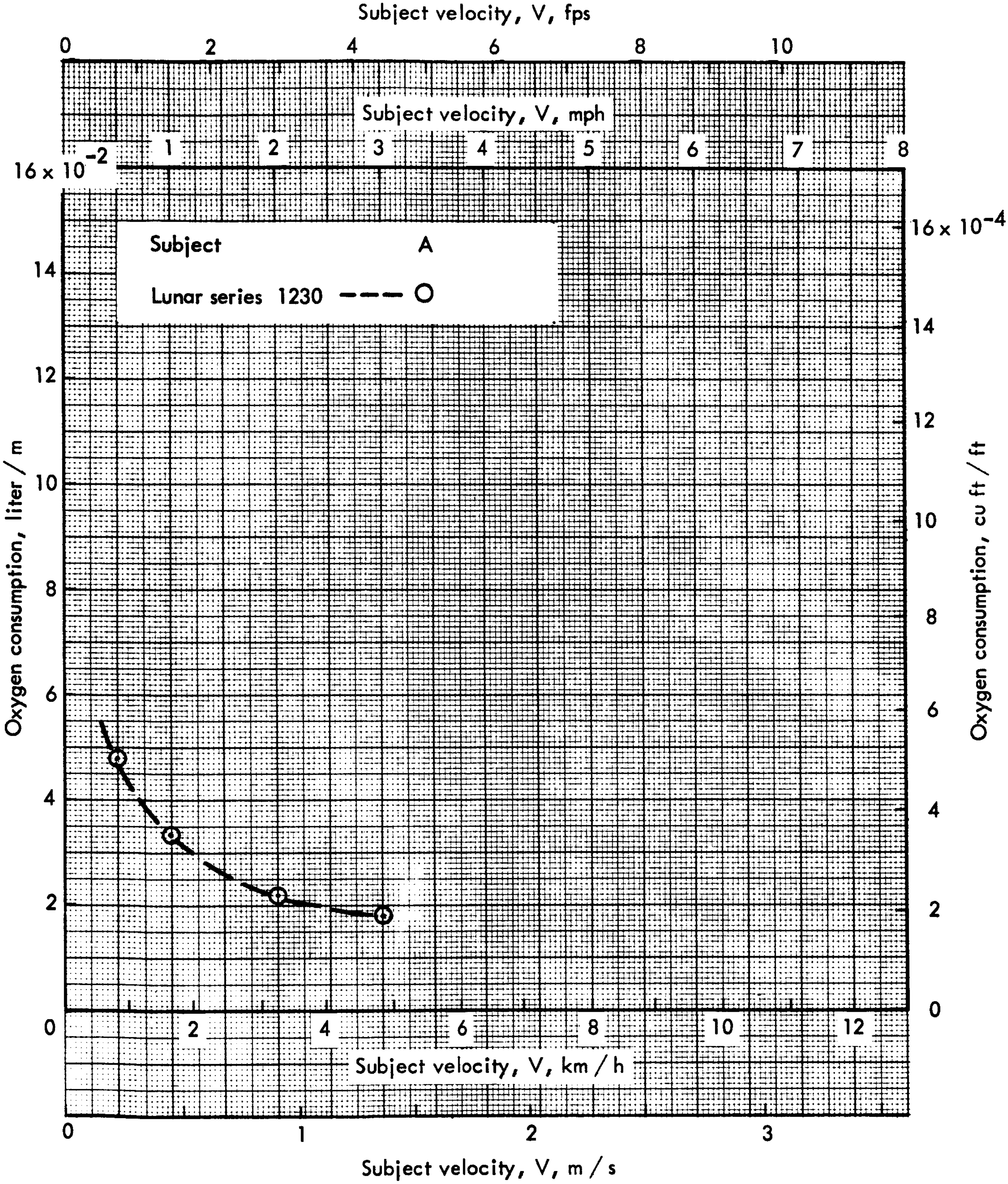


Figure 250. – Oxygen consumption per unit length versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

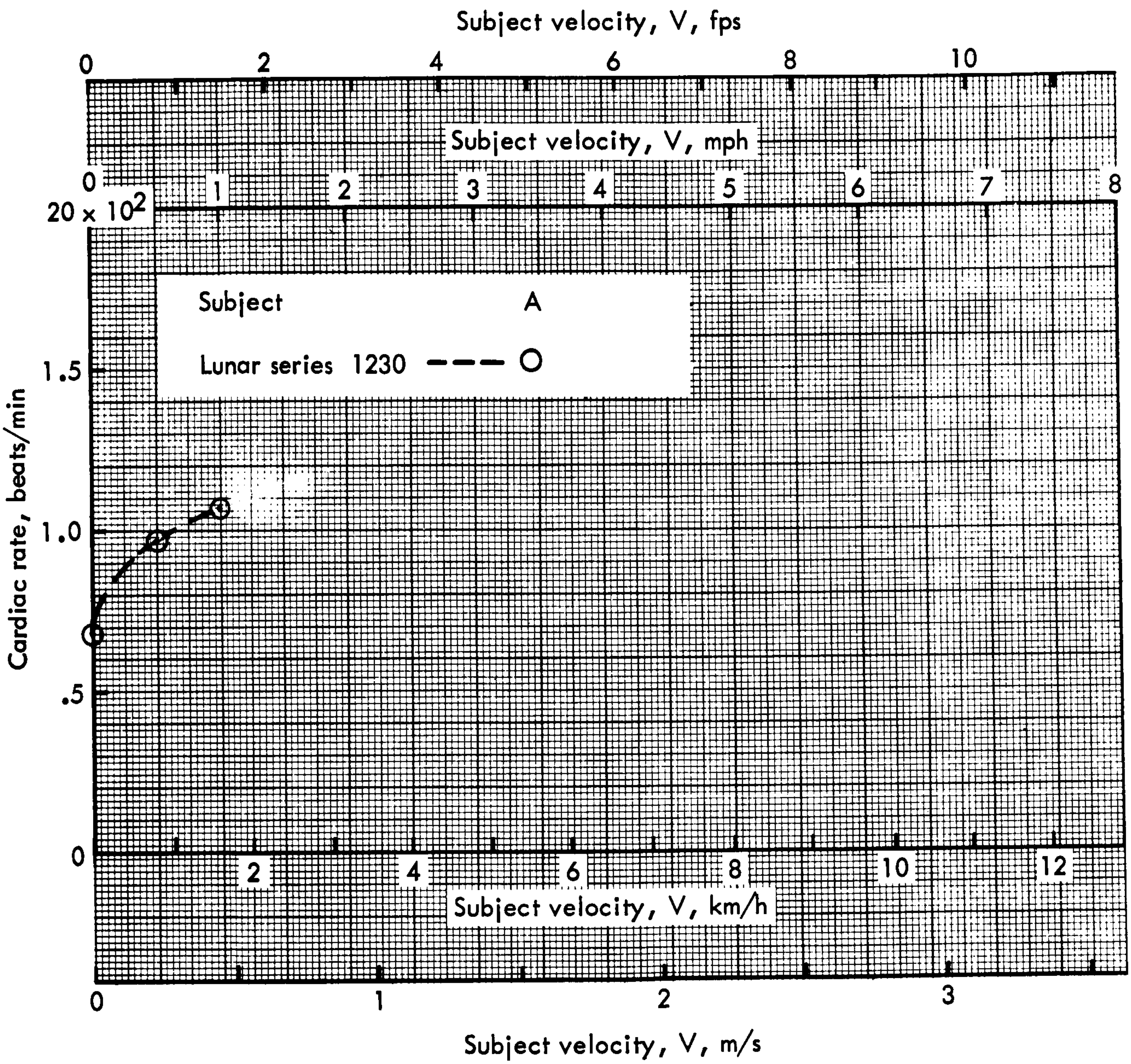


Figure 251. – Cardiac rate versus subject velocity crawling horizontally.
Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

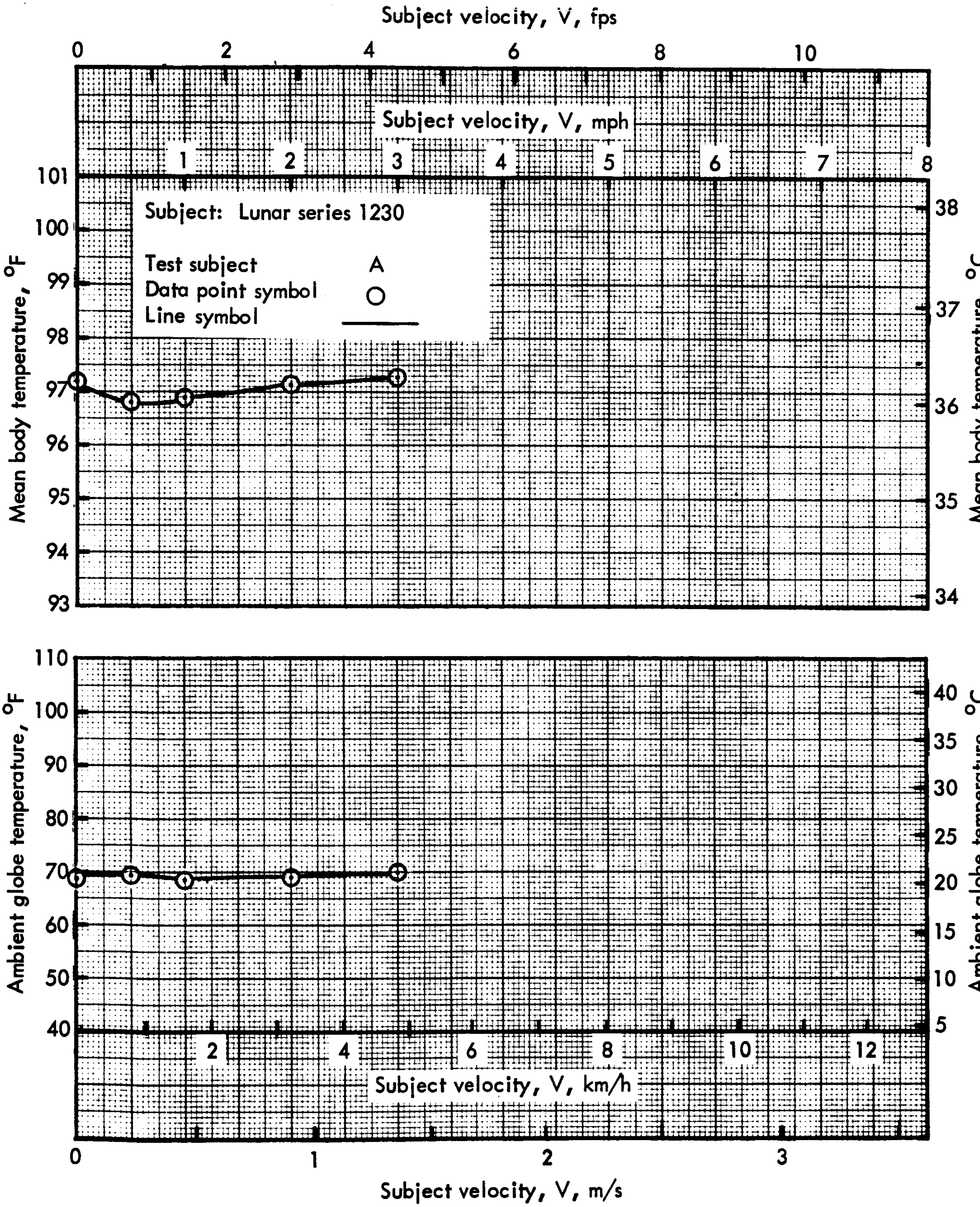


Figure 252. – Mean body temperature (and ambient globe temperature at time of observation) versus subject velocity crawling horizontally.

Test Conditions: 1/6 g, shirtsleeve, susp. gear, pack I

DISCUSSION

The discussion that follows conforms in general to the sequence adopted for the Methods and Results sections of this report. The purpose of this discussion is to point out noteworthy results and comparisons of the data obtained. Table 7 indicates the comparable test modes between earth and lunar gravity for the purpose of establishing the difference in the physiological results. The weight bearing influences of instrument packs I and II. as well as those of the suit pressurization on the physiological results, were also found by comparing the different test modes according to Table 7.

TABLE 7.- DETERMINATION OF INFLUENCES AND DIFFERENCES IN WORK PHYSIOLOGICAL DATA

To establish the differences between earth and lunar gravity:	
for shirt sleeve, Instrument Pack I suspension gear	- compare mode 6000 vs. 1000
for pressure suit vent flow, Instrument Pack II suspension gear	- compare mode 7000 vs. 2000
for pressure suit pressurized, Instrument Pack II suspension gear	- compare mode 8000 vs. 3000
To establish the influence:	
of Instrument Pack I	- compare mode 1000 vs. 5000
of Instrument Pack II and suit vent flow	- compare mode 2000 vs. 5000
of Instrument Pack II and suit pressurized	- compare mode 3000 vs. 5000
of suit pressurized	- compare mode 3000 vs. 2000

In evaluating the physiological data recorded during this program and expressed in the detailed data graphs, it is desirable to keep in mind some of the basic limitations of research on the human body.

In comparison with research on purely physical (non-living) systems, physiological test results are generally much more variable, in some cases unexplainably so. Insight into the complexity of the human mechanism and its patterns of response to activity and environmental conditions helps in interpretations, but cannot always explain unexpected variability in recorded data. Multiple experiments on the same individual, or on a large population, can yield smoother data by application of statistical principles.

The nature of this program was such that few duplicate tests on single subjects could be performed, and there was not a large population of subjects. In general, data points for a given experimental condition represent averages of single measures from one to three subjects.

Due to the physical location of the primary research facility (the LGS) outdoors, environmental conditions were not subject to control. The large number of tests which had to be accomplished within the scheduled time period made it impossible to conduct tests only when environmental conditions fell within limits which could reasonably be considered as "standardized." Variation in the thermal environment (both air tempera ture and mean radiant temperature at the LGS was the primary disturbing factor. Study of the data. in relation to the thermal environment during each test (as evaluated by the globe thermometer) had disclosed significant effects on physiological variables. Where a given activity cycle had to be tested in two or more sessions for a given subject (fortunately true in relatively few cases), it was found that significant differences in environmental temperature caused greater or lesser degrees of nonlinearity in the data points which were intended to show change in individual physiological functions in response to changing level of physical activity. Similarly, where a data graph contains results from two or more subjects, the inevitable occasional difference in environmental conditions in some cases lessens the rigorous comparability of data. In a few cases, effects of changing environmental temperature during a single test session could be recognized.

Variations in subjects' physiological and psychological condition (including differences in motivational level both between subjects and in one subject from day to day) cannot be eliminated and produce effects which constitute one of the most fundamental problems in physiological research, especially on humans.

The combined effects of the factors mentioned above have made the location of "average trend" curves on the individual test graphs much more difficult and less precise than if more tests on more subjects, under controlled environmental conditions, could have been performed. In a few instances, drawing trend curves through points representing the averages of data at each experimental condition made it necessary to modify the curves by intermediate averages.

Considering the foregoing problems, it is gratifying that the graphed data on the whole exhibits good evidence of reliability and consistency. This is true especially in the case of the basic physiological measures such as oxygen consumption, lung ventilation volume, and heart rate most responsive to the intentional variables of the test program and least subject to adventitious influences.

The graphs included in the "Result Section" provide detailed data on the physiological variables which were monitored. These show individual data-points for each subject in the respective test modes and levels of activity. Their principal function is to show, for each test series, the relative response of the given physiological variable as a function of increasing level of physical activity. Trend curves were located on each graph to show the average response (where data were obtained from two or three subjects), subject to the qualification stated previously regarding environmental temperature effects and other disturbing factors.

In order to enable comparison of the results in different test modes, graphs have been prepared which group in different ways the trend-lines from the individual test graphs. These are presented as Figures 253 through 270 in this section of the report. The figure captions, and labelling of the curves, are largely self-explanatory to the reader who is interested in evaluating the relative effects thus portrayed. For that reason, discussion here will be held to a minimum.

Respiratory Minute Volume

The detailed graphic data on respiratory minute volume, contained in the Results section, constitutes some of the most consistent of the physiological data from the program. These data, of course, were obtained from the Mueller-Franz Respirometer, and were subject to fewer artifacts of measurement than some of the other physiological functions monitored. This is shown both by the more consistent relationship between the minute volume and the increasing levels of subject velocity in the various test series.

There are a few instances in which the data spread between subject is abnormally great, indicating the possibility of some technical problem in operation of the system. The most conspicuous of these is in the tests on the treadmill at one g with the suit pressurized (Series 8000). The great differences in minute volume, between subjects A and C, cannot be explained except through possible malfunction of some component of the respiration equipment.

Respiration Rate

Detailed data on the respiration rates recorded for the various tests are contained in the "Result Section".

The difficulty experienced early in the program through erratic operation of the sensor in the exhaled air line sometimes resulted in the loss of respiration rate data.

All three subjects had resting respiration rates in the range of 10 to 12 breaths per minute. During tests, the rates rose to levels which were roughly proportional to the level of energy expenditure and consequent lung ventilation rate requirements. Figures 253 through 256 provide grouped curves for Series 1000, 2000, 3000, and 5500-8000, respectively.

Respiration rate as such is a less significant measure of physiological response to various kinds and levels of activity than minute volume of lung ventilation, since the rate of breathing is influenced by psychological factors as well as the operating characteristics of equipment used, while minute volume is basically determined by physiological requirements in the long run.

Oxygen Consumption and Metabolism

To enable comparison of the differences in oxygen consumption rate in the various test modes, several graphs have been prepared which group the summary curves in various ways. This has not been duplicated for the metabolic rate curves, since they would be substantially identical in their relative positions and would differ significantly only in scale units.

Test Series 1000 and 5000. - Figure 257 presents comparative curves for oxygen consumption rate in the Series 1000 tests of performance on the LGS with the subject in shirtsleeve garb, carrying Instrument Pack I. (One curve from Series 5000, similar except performed without the instrument pack, is also included.)

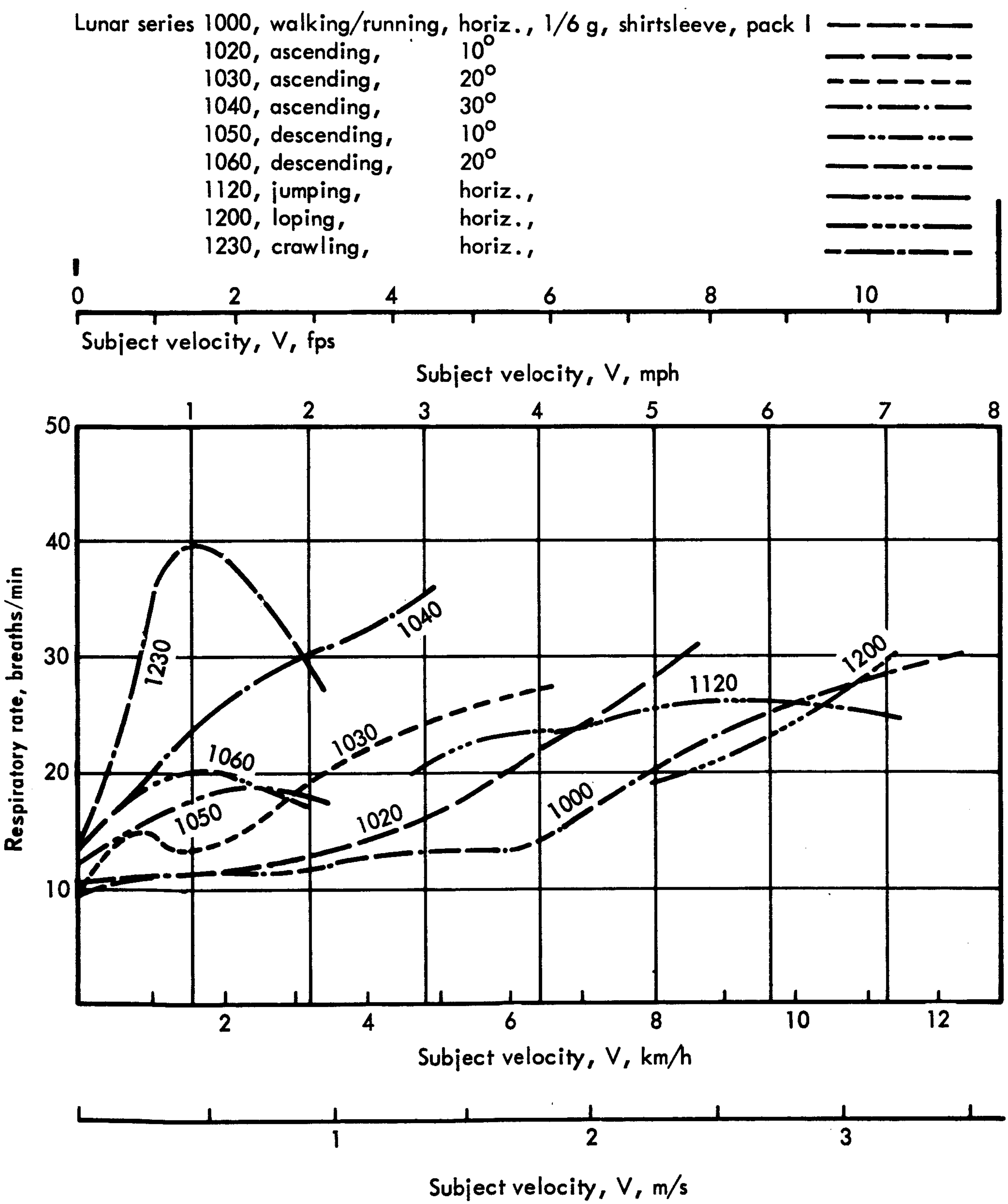


Figure 253. - Respiratory rate versus velocity at 1/6 g; summary of 1000 series shirtsleeve condition with Pack I; walking and running except as noted

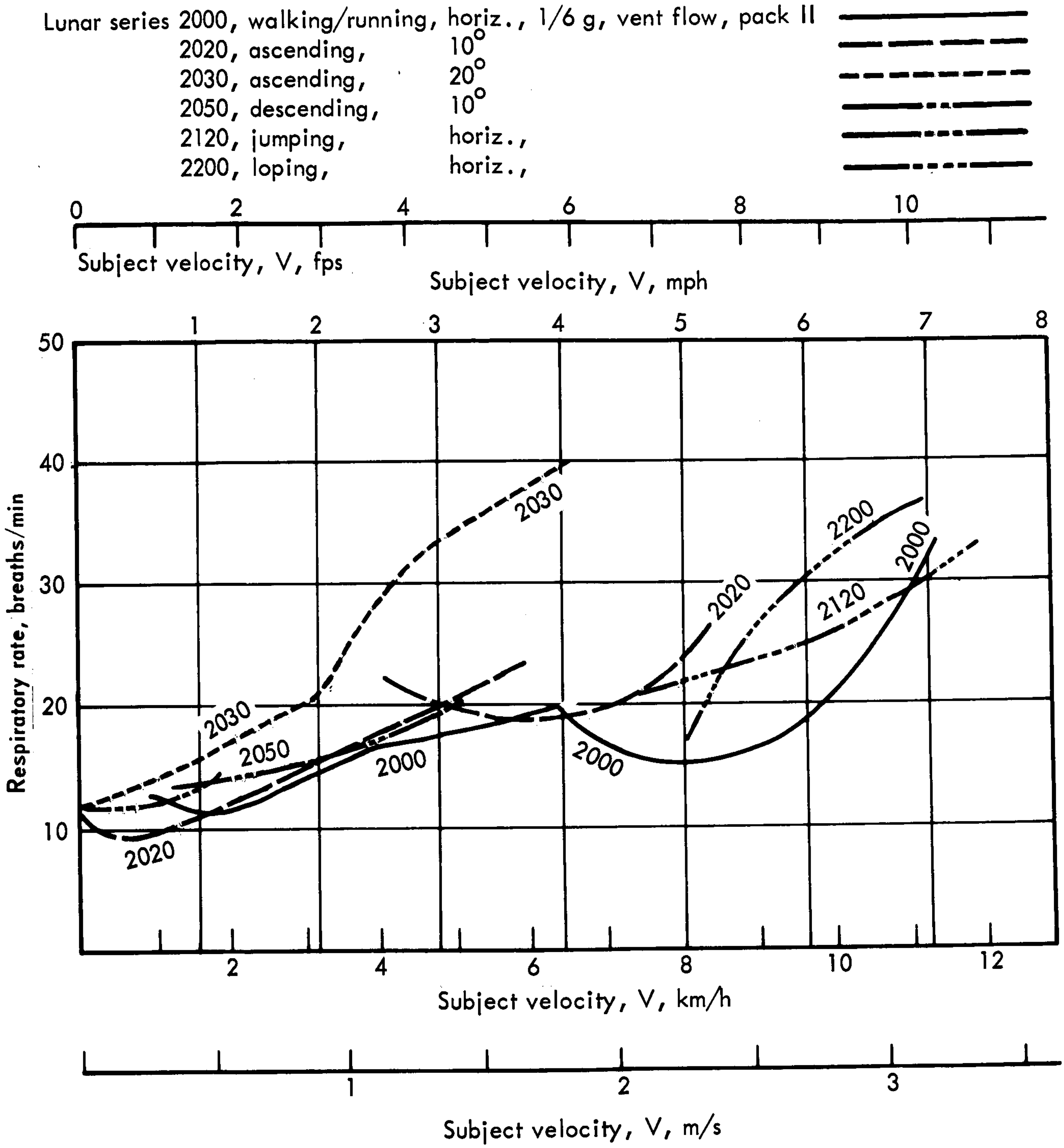


Figure 254. - Respiratory rate versus velocity at 1/6 g; summary of 2000 series: pressure suit-vent flow ; Pack II; walking and running except as noted

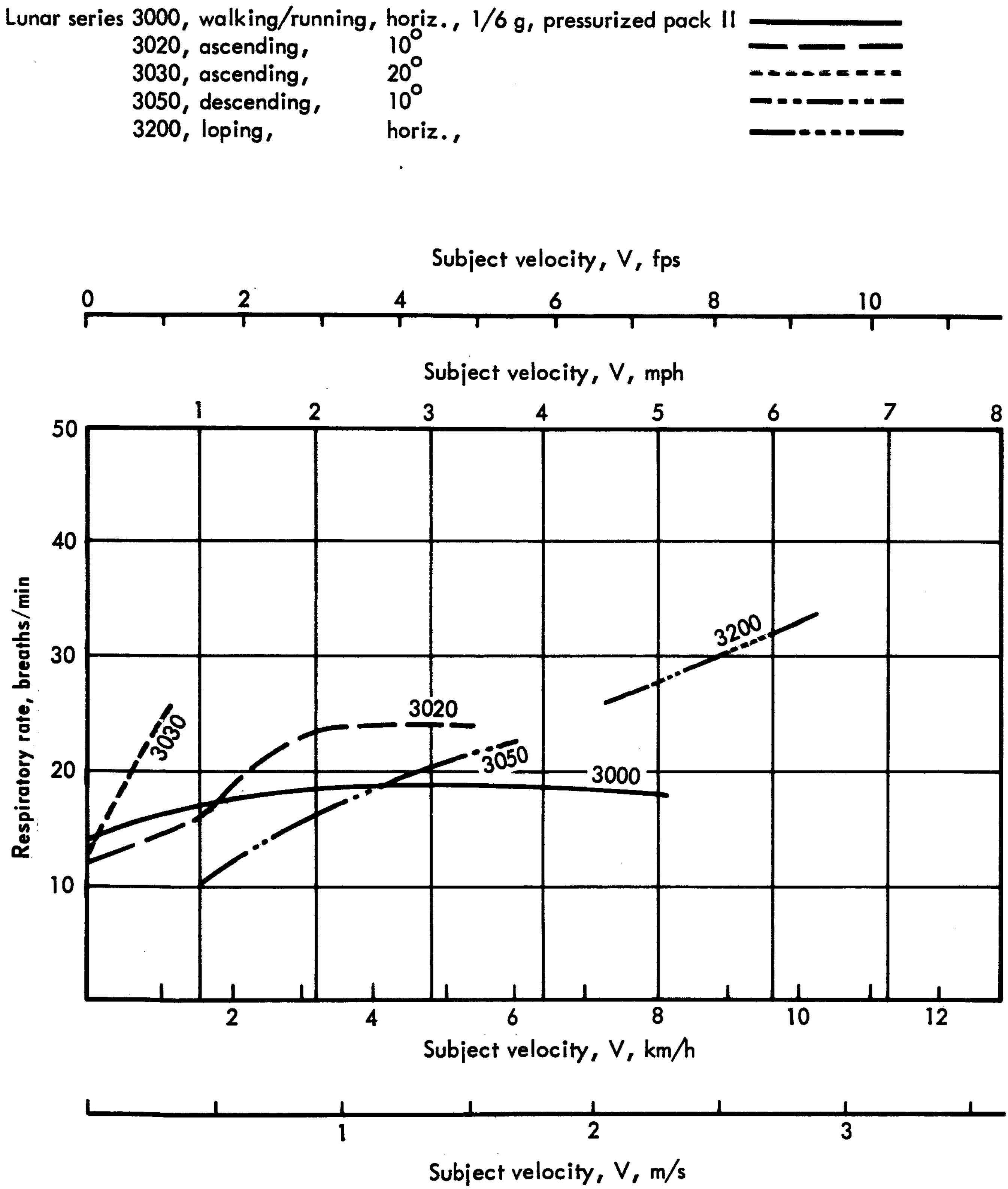


Figure 255. - Respiratory rate versus velocity at 1/6 g; summary of 3000 series; pressure suit (pressurized); Pack II; walking and running except as noted

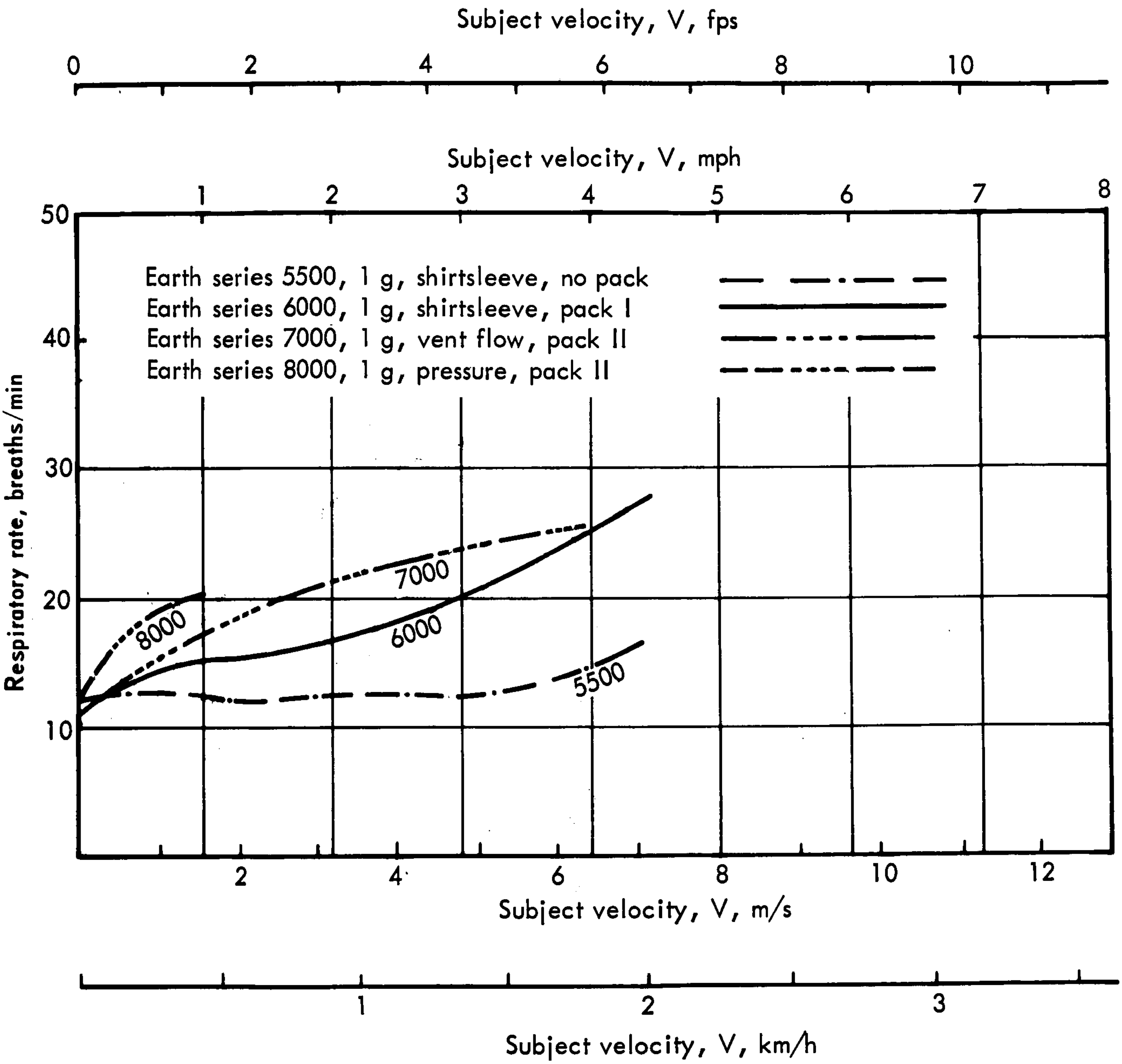


Figure 256. - Respiratory rate versus velocity: summary for 1 g tests; walking and running on level; series and equipment noted; shirtsleeve except as noted.

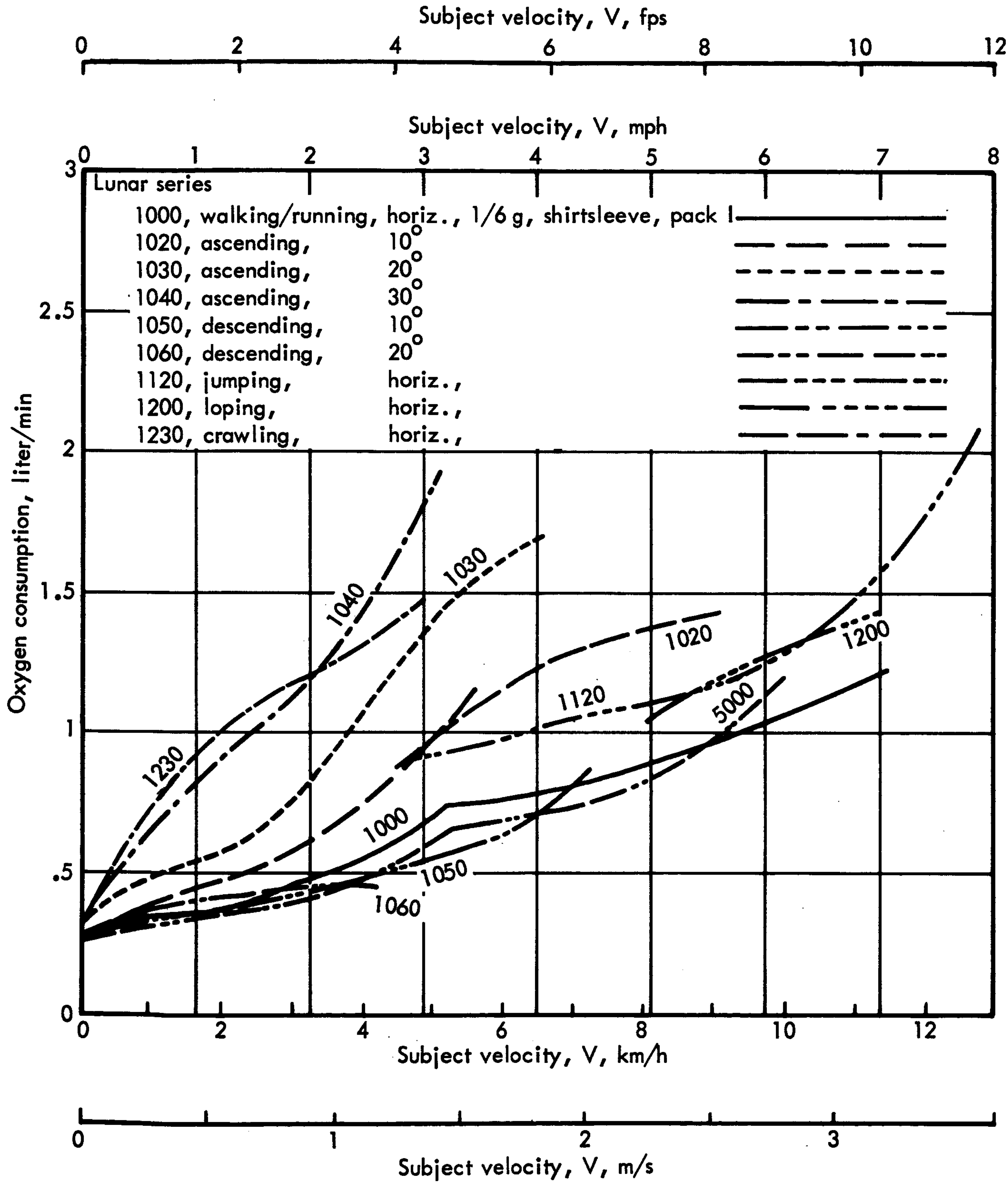


Figure 257. - Oxygen consumption versus velocity at 1/6 g; summary of 1000 series; shirtsleeve with Pack I; walking and running except as noted

A minimum envelope of oxygen consumption vs subject velocity is seen, rising from about .5 to .6 ℓ/min with the subject standing at rest, to about 1.2 ℓ/min in level running at 7 mph. Values for the Series 5000 run, without pack, were generally slightly lower. Those for walking descending at 10° and 20° grade angles were in the same range of values for the velocities achieved.

Values for ascending the 10°, 20° and 30° degree grades, were correspondingly higher, as would be expected. The activity cycles of horizontal loping and horizontal jumping, performed only at the higher velocities, showed oxygen consumption rates approximately 20 to 25 per cent greater than running on the level at the same velocities, i.e., in the range of 1 to 2 ℓ/min.

The single curve for horizontal crawling showed a consumption rate approximately the same as for ascending a 30° slope.

Test Series 2000 and 3000. - Figures 258 and 259 summarize the oxygen consumption rates for tests in the pressure suit on the LGS, the former for activity with the suit unpressurized (ventilation airflow only), the latter for the pressurized condition. Aside from the obvious effect of grade climbing, the most interesting indication from the curves in both groups is that consumption rates were almost the same for all methods of progression on the level: walking-running, loping and jumping.

The trend curves in Figure 259, (suit pressurized) show peculiarities of configuration which reflect the fact that technical problems of measuring oxygen consumption in a pressurized suit, especially with the subject in relatively violent physical activity on the LGS, are considerably greater than for corresponding measurements on shirtsleeved subjects walking on a treadmill in the laboratory.

Test Series 5500-8000. - Figure 260 groups the data obtained for walking and running on a treadmill at one g, with various combinations of clothing and load carried. Effects of added load, of grade climbing (shirtsleeve only), and of wearing the suit both unpressurized and pressurized, are obvious and will not be commented on here.

Test Series 1180, 2180 and 3180. - A separate graph, Figure 261, shows comparative results from the three series of stair climbing tests on the LGS: Series 1180 (shirtsleeve), Series 2180 (unpressurized suit) and Series 3180 (pressurized suit). The technical problems experienced in these three tests, so far as physiological measurements were concerned, were even greater than the LGS tests in which the treadmill could be used. The reliability of the data is open to considerable question, as is shown in part by the paradoxical indication that oxygen consumption for stair climbing in the unpressurized suit was lower, for all velocities, than for shirtsleeve climbing, and that values for the pressurized suit test were seemingly independent of velocity.

In order to use the known parallelism of heart rate and oxygen consumption, a plot of heart rates for the three series was also included in Figure 261 (lower section). The curves for Series 1180 and 2180 would seem to corroborate the relative oxygen consumption values discussed above, so the paradoxical relationship is for the present unexplained, except possibly through the factor of considerable more training.

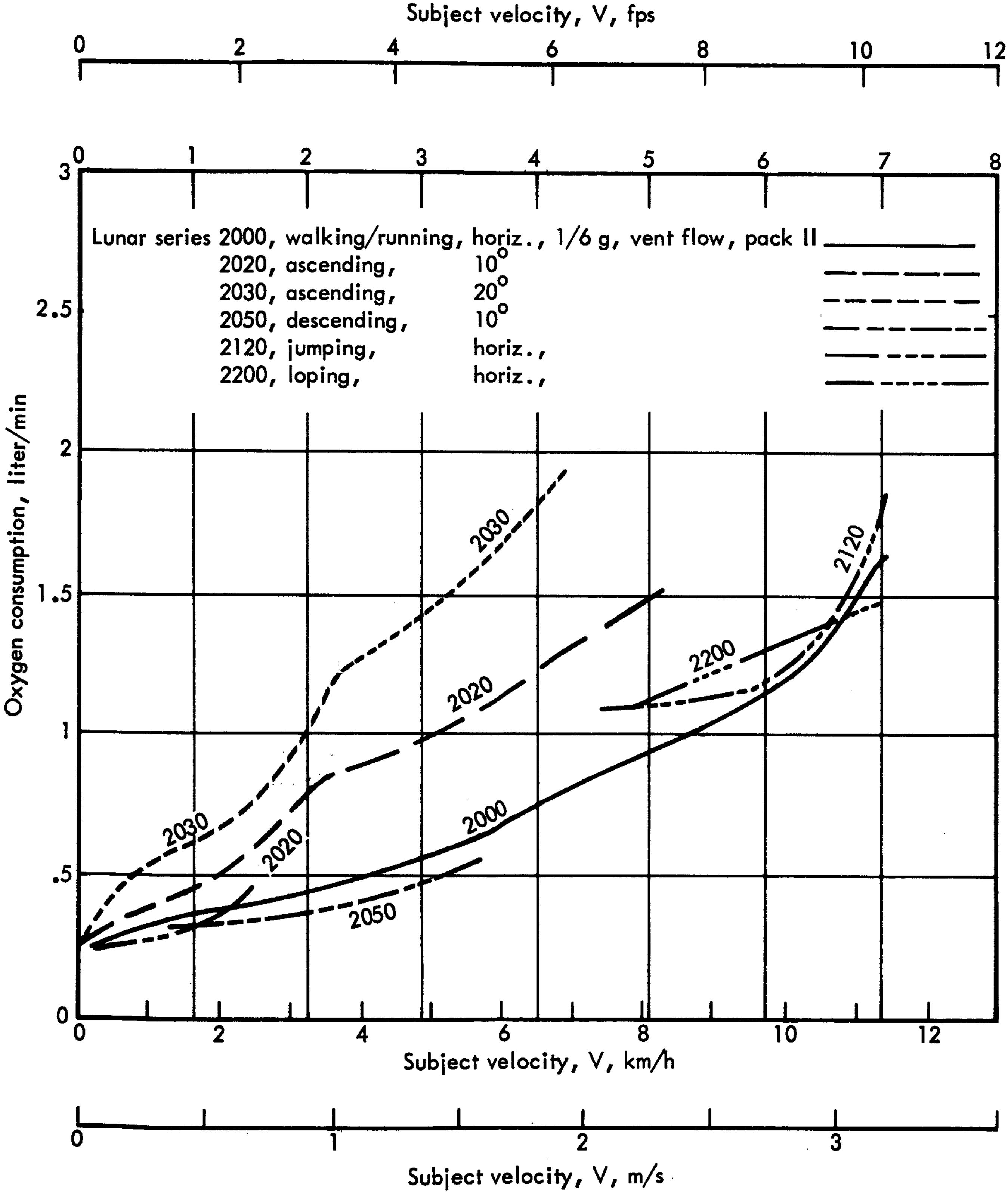


Figure 258. - Oxygen consumption versus velocity at 1/6 g; summary of 2000 series; pressure suit (vent flow only) with Pack II; walking and running except as noted

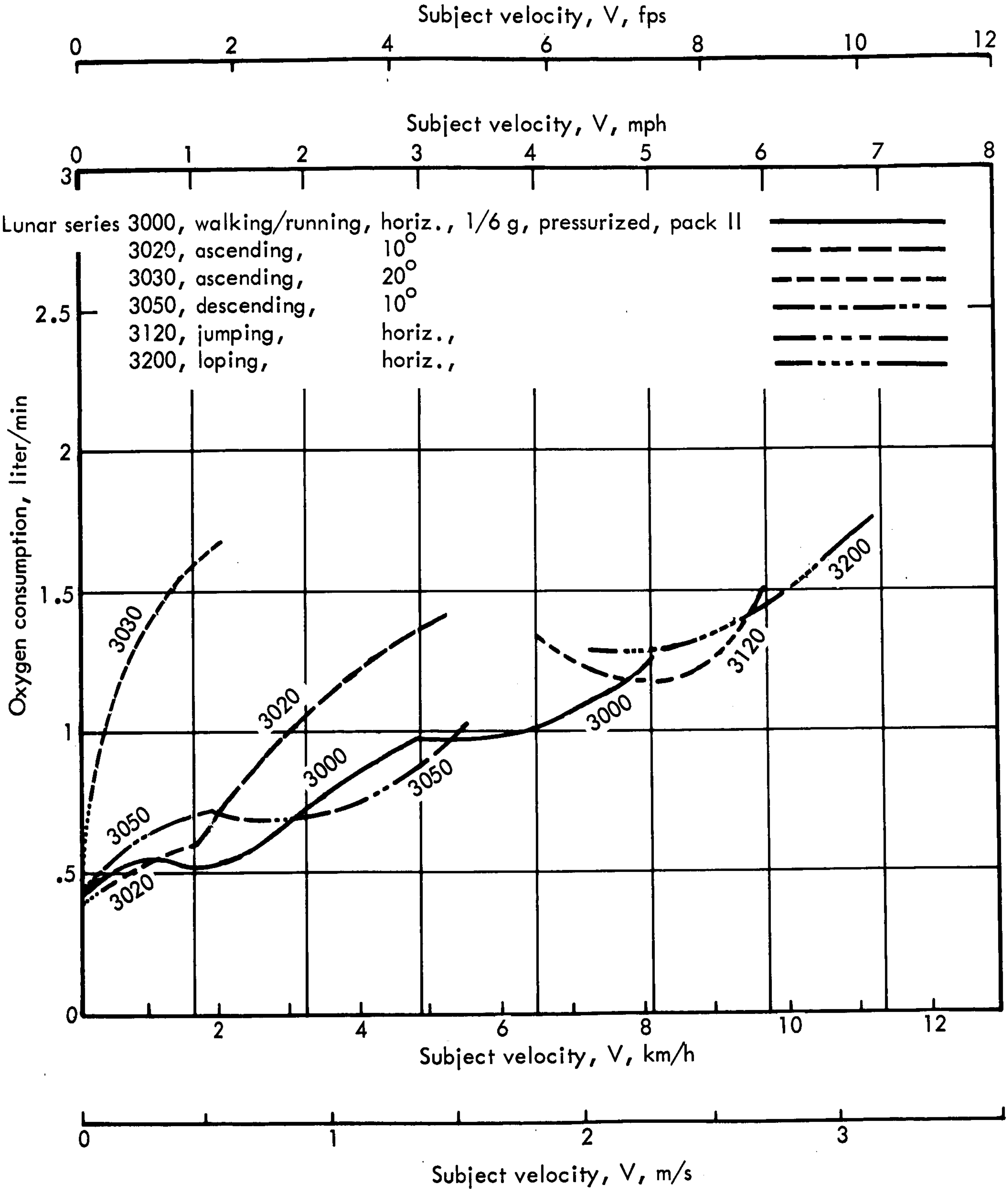


Figure 259. - Oxygen consumption versus velocity at 1/6 g; summary of 3000 series; pressure suit at 3.5 psi, with Pack II; walking and running except as noted

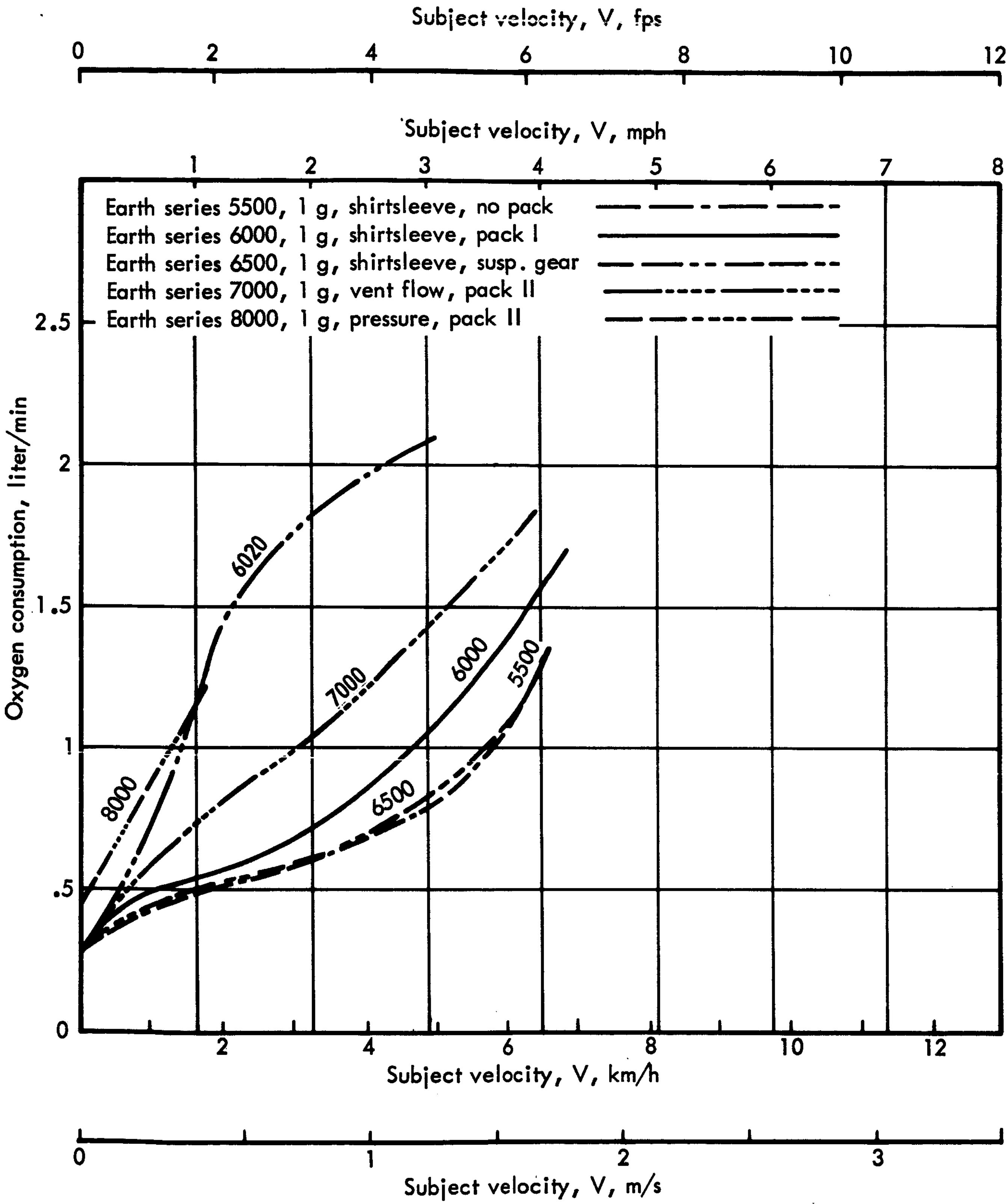


Figure 260. - Oxygen consumption versus velocity, summary for walking and running at 1g; test series number noted; see code block and curve labels for test conditions, clothing and equipment carried

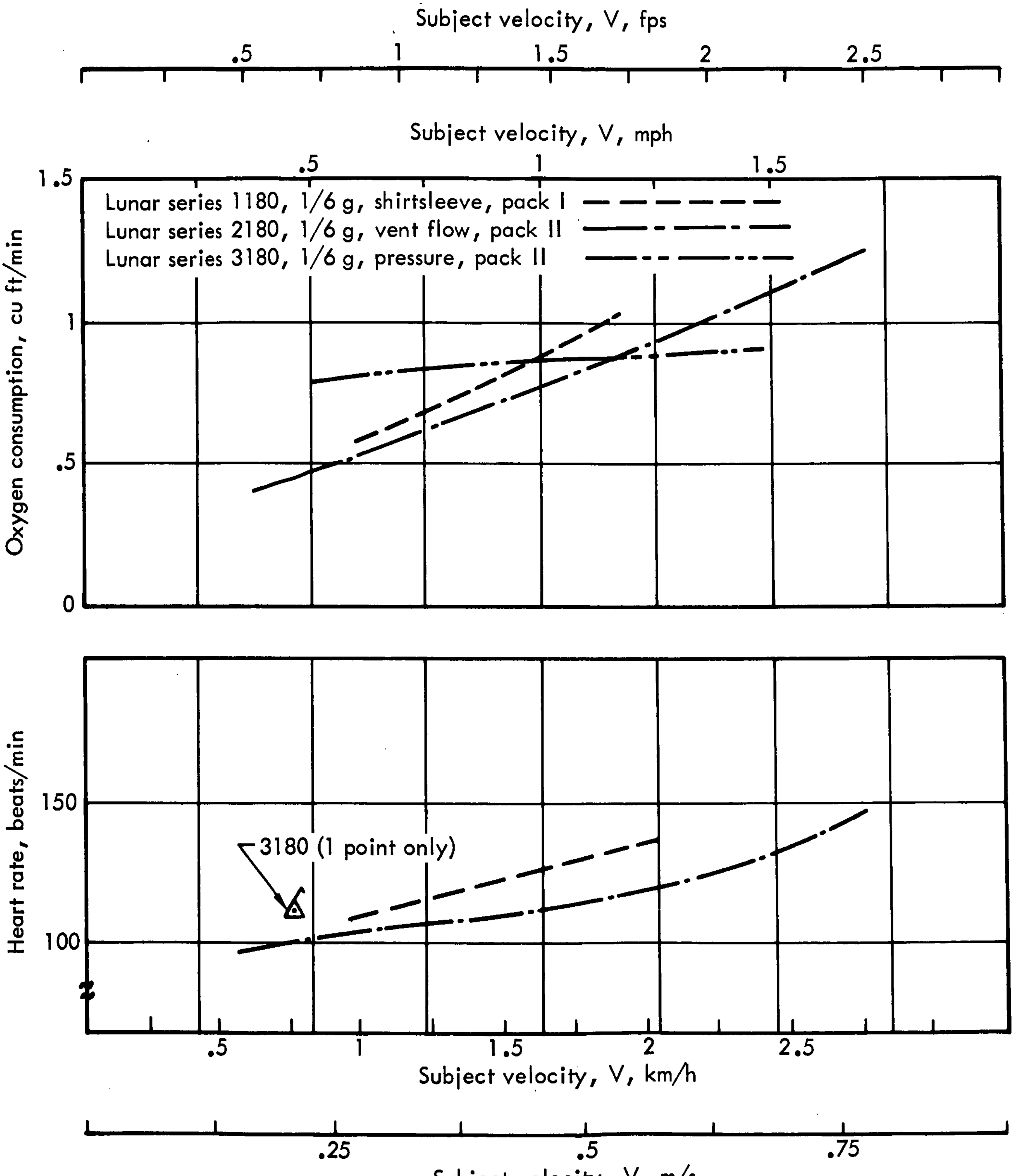


Figure 261. – Summary of heart rate and oxygen consumption for stair stepping. Comparison of 1/6 g, test conditions between shirtsleeve, vent flow and pressure

Inter-Series Comparisons. - Figures 262 and 263 group the data on walking and running on the level and on up and down grades, both on the LGS and at 1 g. They show the relative effects of the clothing, load and gravitational variables in the program. Of particular interest are the differences between the oxygen consumption at 1/6 g and at one g, in activities with identical clothing and load conditions. Paired comparisons are provided by the curves for the following series:

Shirtsleeve condition; 1/6 vs one g: 1000 vs 6500.

Unpressurized suit; 1/6 g vs one g: 2000 vs 7000.

Pressurized suit; 1/6 g vs one g: 3000 vs 8000.

Pack vs no pack at 1/6 g: 1000 vs 5000.

Unpressurized vs pressurized suit; at 1/6 g: 2000 vs 3000.

at one g: 7000 vs 8000.

Effect of LGS suspension gear at one g: 5500 vs 6500.

From Figure 262 it may be seen that at 1/6 g, there was little significant difference in oxygen consumption rates, walking or running on the level in the shirtsleeve condition with or without the instrument pack (possibly slightly lower without the pack), or in the unpressurized suit with the instrument pack.

Suit Pressurization. - On the LGS, in the middle range of subject velocities (3 to 5 mph), it is evident that the greater resistance to body movement offered by suit pressurization (3.5 psi above ambient) increased oxygen consumption considerably. It appears that if the increase in oxygen consumption over the resting level is chosen as the basis of comparison, suit pressurization nearly doubles oxygen consumption for walking in the middle range of velocity on the LGS.

With the subjects wearing the pressurized suit on the treadmill at one g, the effort of walking was so great that total physiologic strain (of which oxygen consumption was only one measure) limited subject velocity to 1 mph, while on the LGS it was possible to achieve 5 mph with the suit pressurized, with no greater rate of oxygen consumption. It even appears that the physiologic cost of progression on the level on the LGS, at 5 mph, was no greater than walking 4 mph at one g in the shirtsleeve condition without a pack, or 3.7 mph at 1 g, shirtsleeve with pack. The same general picture is seen in the data for grade walking and running. These important relationships are seen illustrated in Figure 262 and represent one of the most significant findings of this study.

Even with allowance for the lack of statistical validation of the data from this program, because of the limited number of tests performed for each type and level of activity in the pressurized-suit condition, the oxygen cost of walking or running at 1/6 g is a great deal lower, in the velocity range of 1 to 5 mph, than at one g.

This finding is tremendously significant because it demonstrates that prediction of the metabolic cost of activity in pressurized suits on the moon's surface cannot validly be established by physiologic tests conducted at one g. It also shows that the physiological requirements for locomotion over the moon's surface (in terms of oxygen required and heat produced for covering given distances) cannot be predicted from results of one g

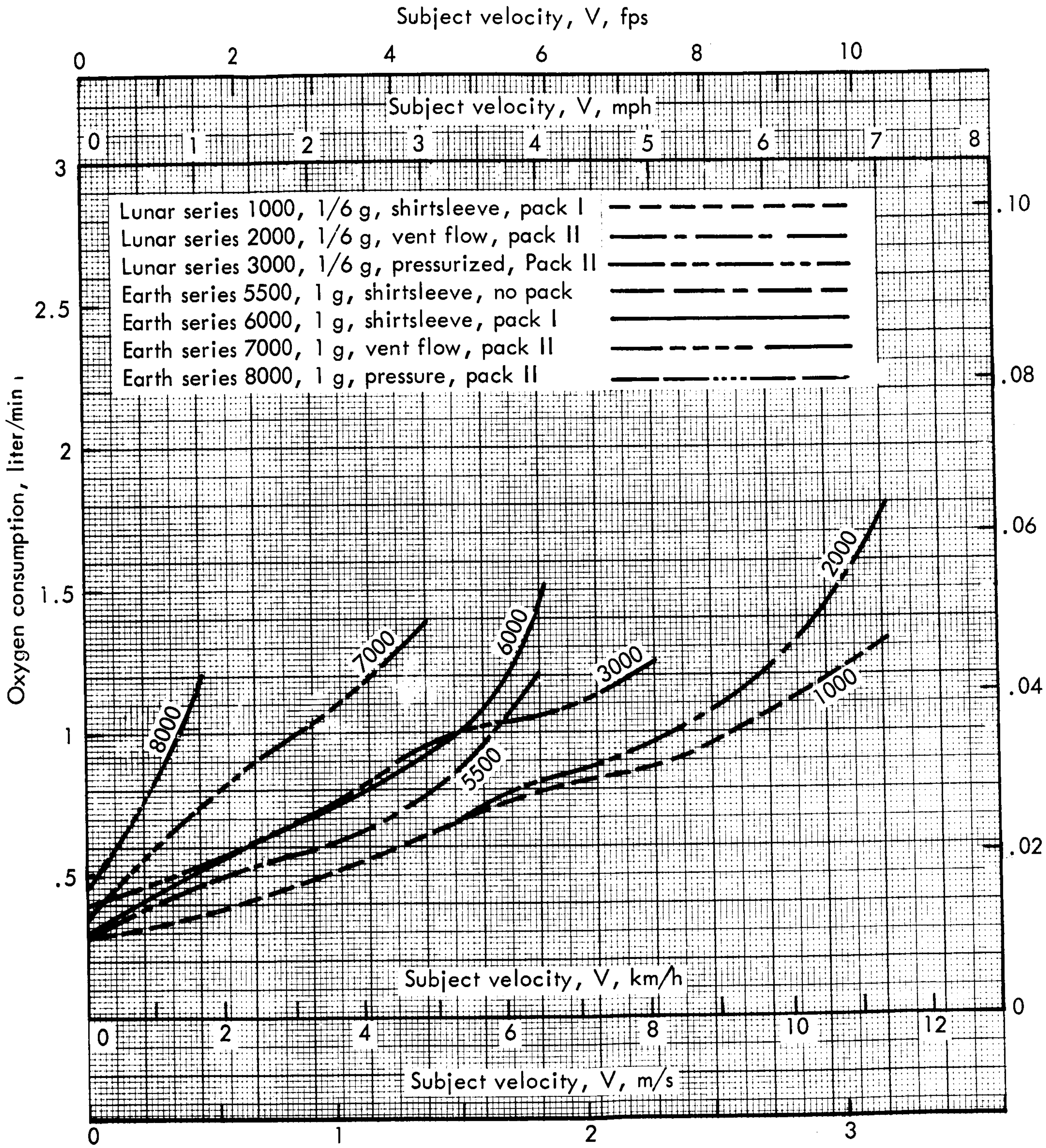


Figure 262. – Average oxygen consumption versus subject velocity, walking and running horizontally.

Comparison of 1/6 g and 1 g test conditions between shirtsleeve, vent flow and pressure.

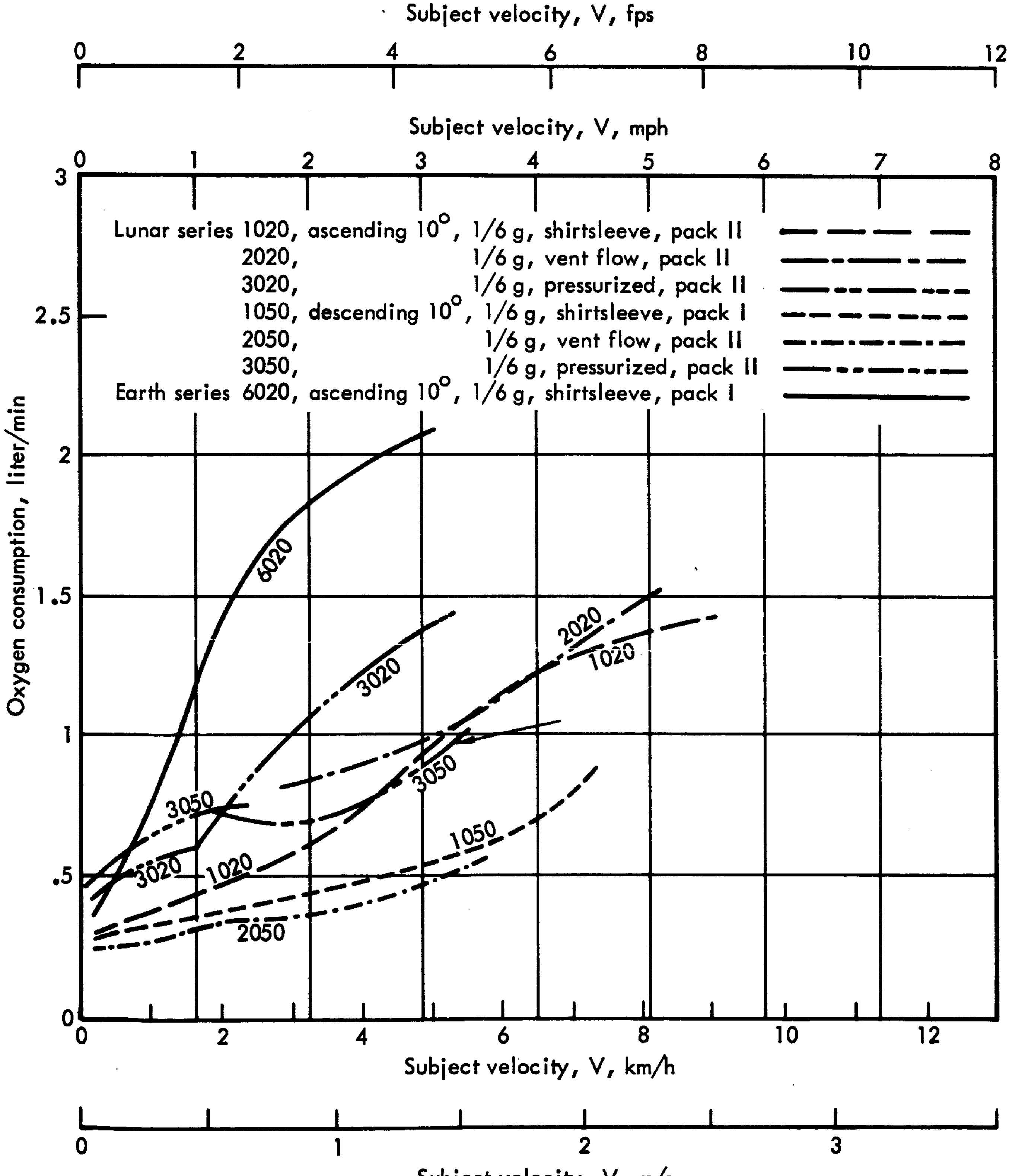


Figure 263. – Oxygen consumption versus velocity, walking and running ascending or descending at 10 degrees at 1/6 g and 1 g; test series number, clothing and equipment load as noted.

research on work physiology accumulated in the past. The reduced rate of metabolic heat production, for various rates of progression (and presumably for all "work" activities involving handling of various masses) is especially significant in relation to requirements for design of environmental control systems.

In that regard, however, it should be kept in mind that although the metabolic requirements for given activities on the moon may be a fraction of what they are at earth gravity, the astronauts, for this reason, may augment their activities (using greater velocities in self locomotion and handling greater loads), governing these activities in terms of physiological strain levels (such as lung ventilation and oxygen consumption levels, heart rate, etc.) comparable to those which impose basic limitations to physical activity here on earth.

The values of oxygen consumption in walking and running in the shirtsleeve condition at one g, obtained in this program, appear to be generally comparable with average values from other studies. Direct comparison is somewhat difficult because of the fact that most past physiological research on grade walking has been at grade increments of 5 per cent, rather than in increments of 10 degrees, which were employed in this program because of the much lower work-lift values at a given grade, under the 1/6 g environment.

The minimum grade used in this program was 10°, which is a 17.4 per cent grade -- considered a rigorous climbing task in conventional exercise physiology research at one g. In fact, this grade is near the end-point of performance of many subjects in the Balke test for physical fitness, which was used for subject evaluation and is described in Appendix A of this report. Oxygen consumption at 1 mph at one g on the 10° grade, carrying Pack I (see curve 6020 in Figure 263) was approximately 1.2 liter/min. This is very close to average data from other studies, extrapolated to this grade.

On the LGS, the comparable test (curve 1020) showed an oxygen consumption of approximately .44 ℓ/min. This is only 1/3 as great, in total, as at one g. If the comparison is made on the basis of the increment only, over the baseline (standing resting) level, the oxygen cost for the 10° grade climb at 1/6 g (approximately .2 ℓ/min) is seen to be only about 1/5 of the comparable increment at one g (approximately 1.0 ℓ/min.)

Respiratory exchange ratio; respiratory quotient. — In the course of the analysis of the data from the measures of lung ventilation, oxygen consumption and carbon dioxide output in this program, values for the ratio of carbon dioxide output to oxygen consumption were tabulated, but will not be included in this report. In general, values tended to correspond to the expected range of values obtained in studies of work physiology: i.e., from about .75 to somewhat above 1.0. It was quite evident that the activity cycles employed in the program sometimes affected breathing.

In this connection it is preferable to use the latter term for the CO_2/O_2 ratio, as measured in expired air. Rossier et al (ref. 9) and Richards (ref. 10) stress the need for distinguishing between "tissue RQ" and "Ventilation RQ", the latter being preferably designated as the RER. Rossier et al present data on the time course of

change in RQ during the early minutes of exercise, and state that at moderate levels of activity. the RQ tends to stabilize at values between .9 and 1.0, although the measured RER may rise to values as high as 1.2 to 1.4 or above, due to "washing-out" of carbon dioxide if the type of physical activity induces unusually high values of lung ventilation.

The effect of high lung ventilation rates on RER is discussed at length by Haggard and Greenburg (ref. 11). Their extensive study, published in 1935, is relatively seldom cited.

Issekutz and Rodahl (ref. 12) have also rigorously examined respiratory quotient during exercise, and distinguish between "metabolic CO_2" and "nonmetabolic excess CO_2", which they postulate is due to anaerobic metabolism resulting in increasing levels of lactic acid in the blood. According to their data, obtained in studies using a bicycle ergometer, blood lactate rise was first noted at oxygen consumption rates in the vicinity of 1.7 l/min, and increased progressively with higher oxygen consumption rates. This could well explain the high CO_2 outputs observed in the very strenuous physical activity at higher subject velocities, particularly in the Earth g environment.

Cardiovascular Function

Figures 264 through 269 are heart rate summary curves, grouped similarly to the oxygen consumption grouped curves. Not quite as many heart rate curves as oxygen consumption curves were obtained, because greater technical difficulty was encountered in pickup, transmission and recording of heart impulses, especially during the more strenuous physical activity levels.

The heart rate curves may be evaluated generally in the same terms as those on oxygen consumption, since these are parallel functions. There is a growing literature validating the parallelism of heart rate and oxygen consumption; it is even proposed that if subjects can be maintained in satisfactory thermal equilibrium, heart rate might be used as an indirect measure of metabolic rate where measurement via respiratory gas exchange is difficult, unreliable or unfeasible (refs. 13-18). It is recognized that to achieve satisfactory validity of data, it is necessary to "calibrate" subjects by conducting an adequate number of preliminary experiments in which simultaneous determinations of heart rate and respiratory gas exchange are performed over a wide range of physical activity levels, preferably with periodic re-checks.

Body Temperature

Variations in environmental temperature both during the test series as a whole, and even during individual tests, complicated the interpretation of data on body temperature. Effects have been seen regardless of whether the subject was in the "shirt-sleeve" environment in ordinary clothing, or in the pressure suit. The suit was supplied with ventilating air from a source providing some degree of temperature control. A flow rate of 4 cfm was kept constant regardless of whether the suit was used unpressurized, or pressurized to 3.5 psig. The fact that the suit ventilating air had to be delivered through the long umbilical line made it responsive to the ambient temperature, more so than had been expected.

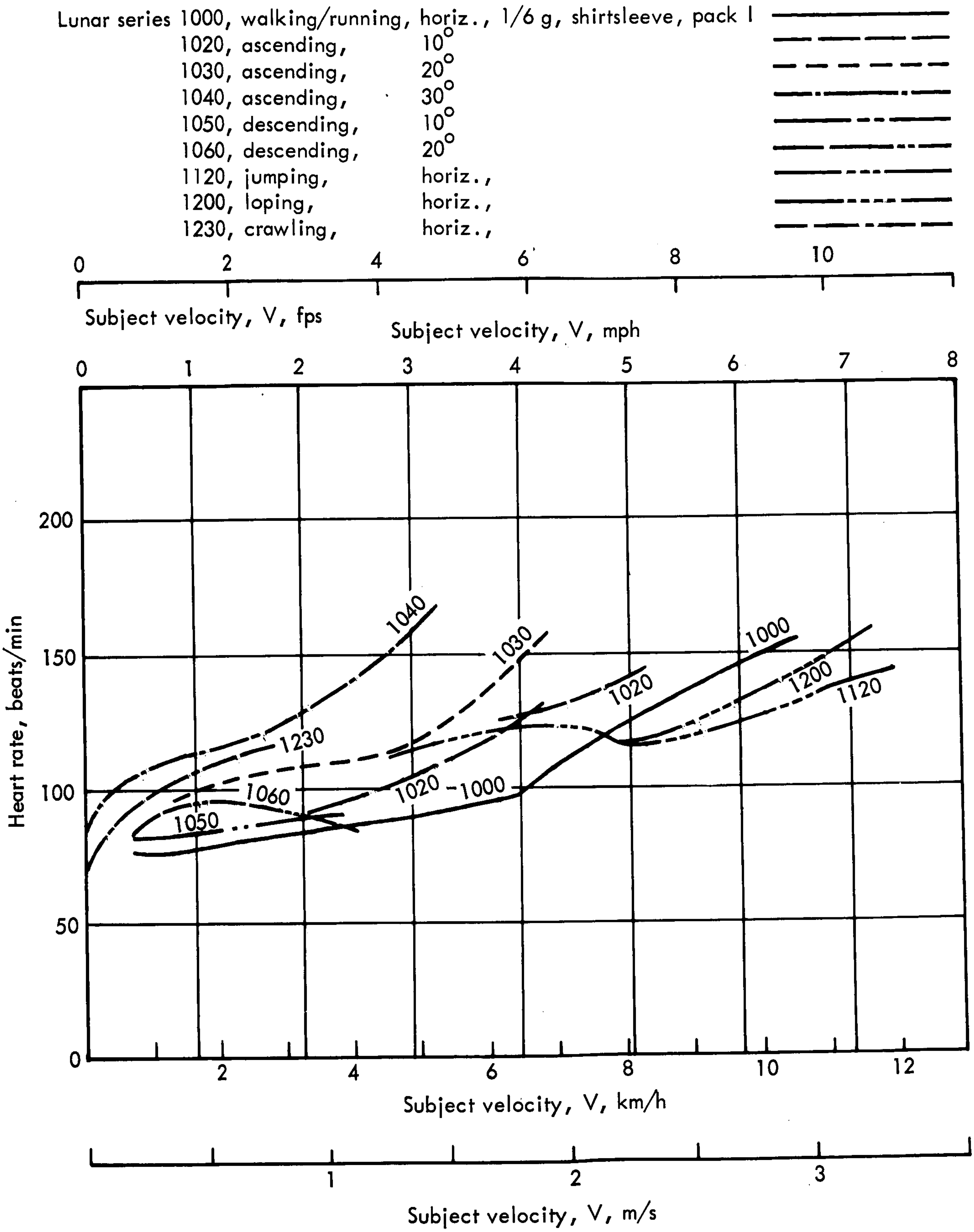


Figure 264. - Heart rate summary for 1000 series at 1/6 g; shirtsleeve condition with suspension gear and Pack I; walking and running except as noted

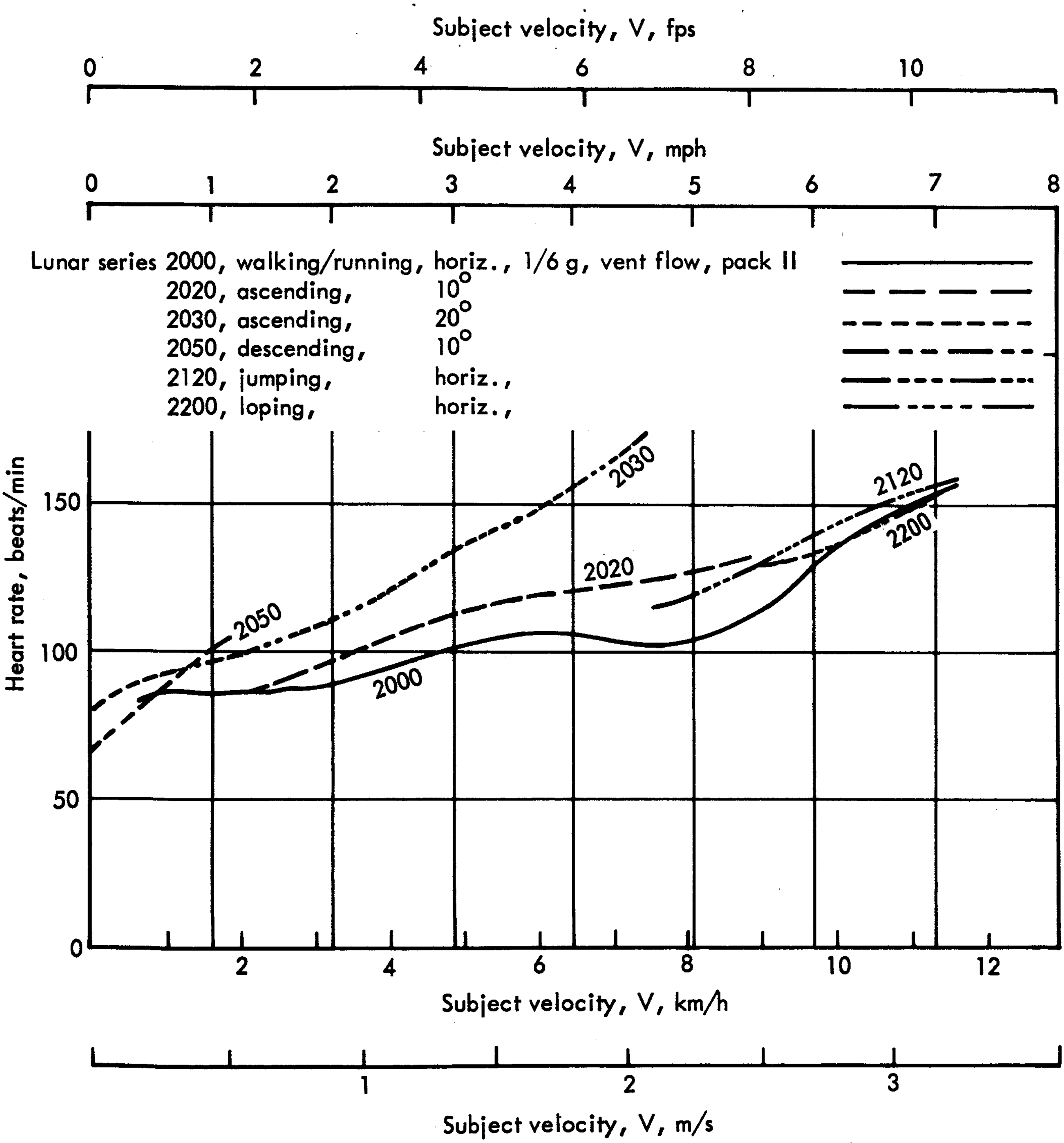


Figure 265. - Heart rate summary for 2000 series at 1/6 g; pressure suit (vent flow only); suspension gear and Pack II; walking and running except as noted

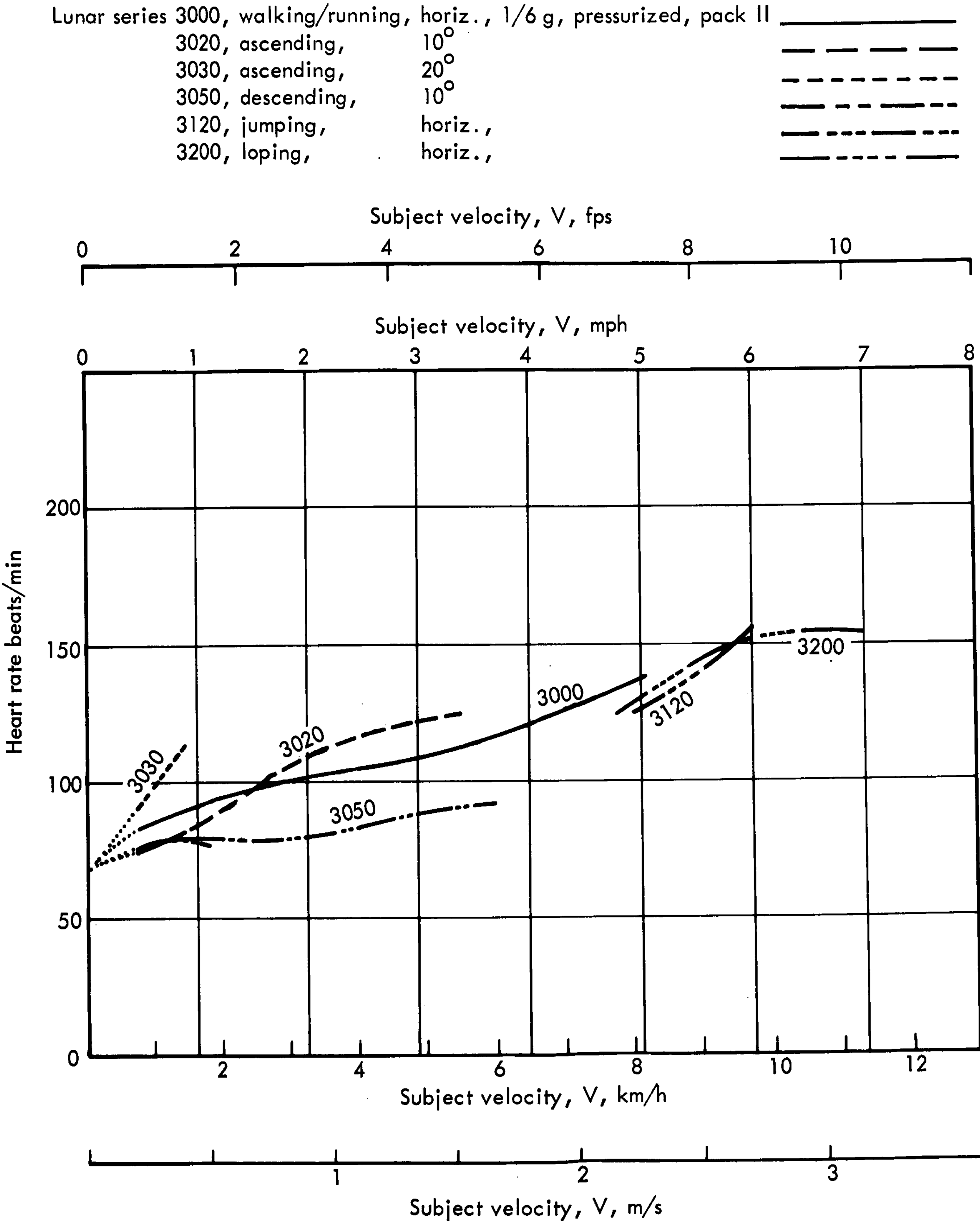


Figure 266. - Heart rate summary for 3000 series at 1/6 g; pressure suit at 3.5 psi; suspension gear and Pack II; walking and running except as noted

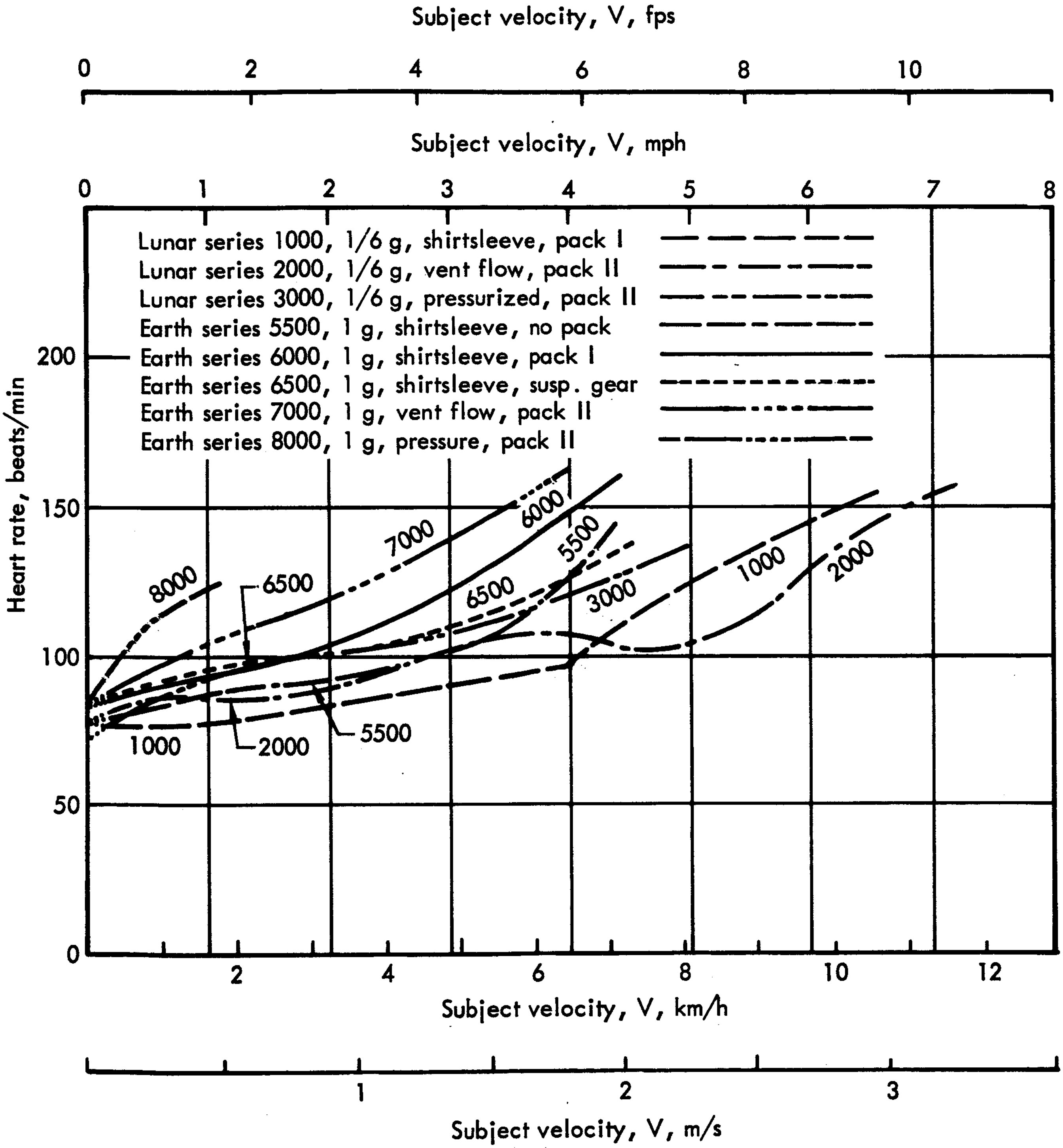


Figure 267. - Heart rate summary for level walking and running at 1/6 g and 1 g; test series number, clothing and equipment load as noted

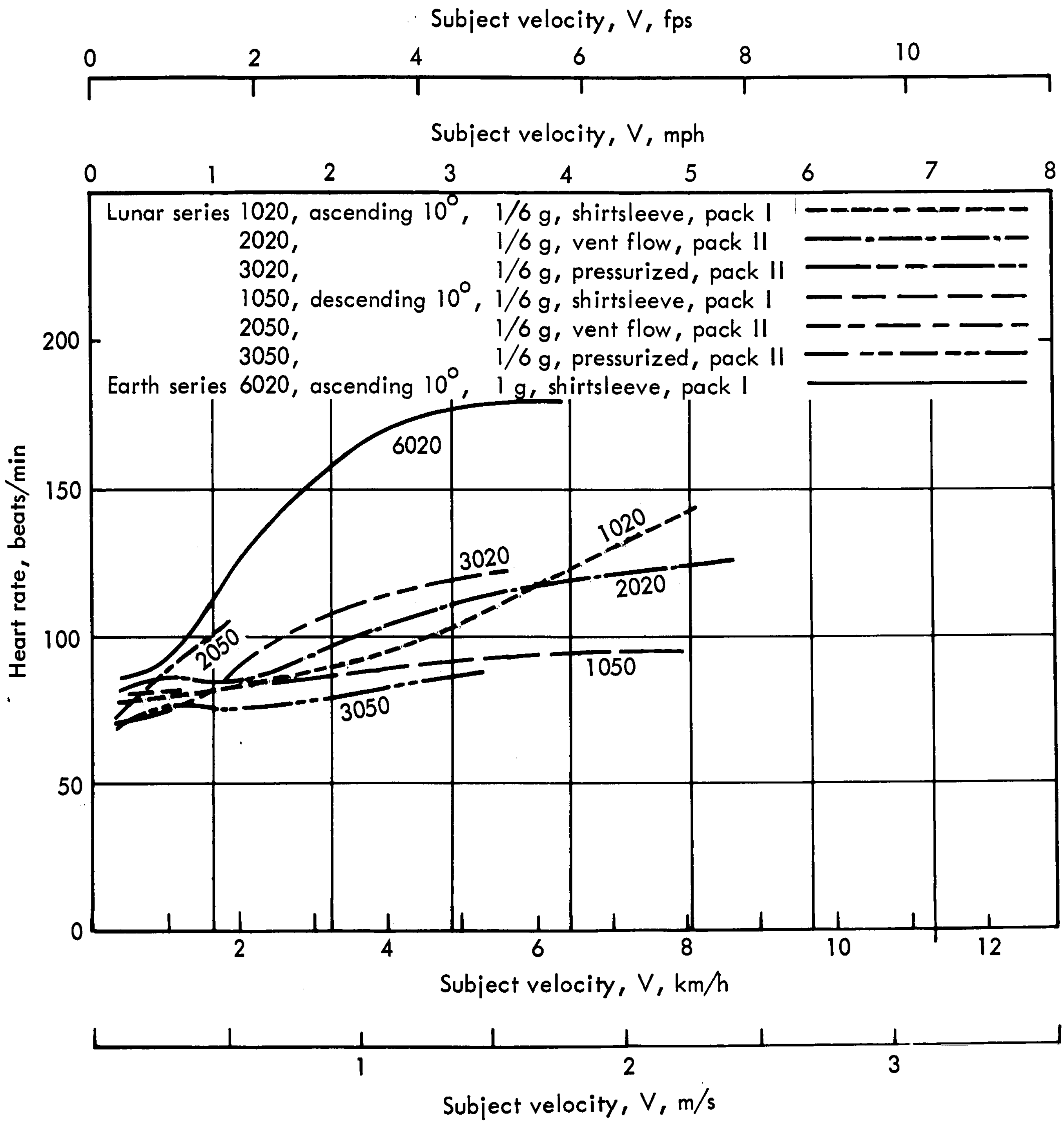


Figure 268. - Heart rate summary for 10° grade walking and running at 1/6 g and 1 g; test series number, clothing and equipment load as noted.

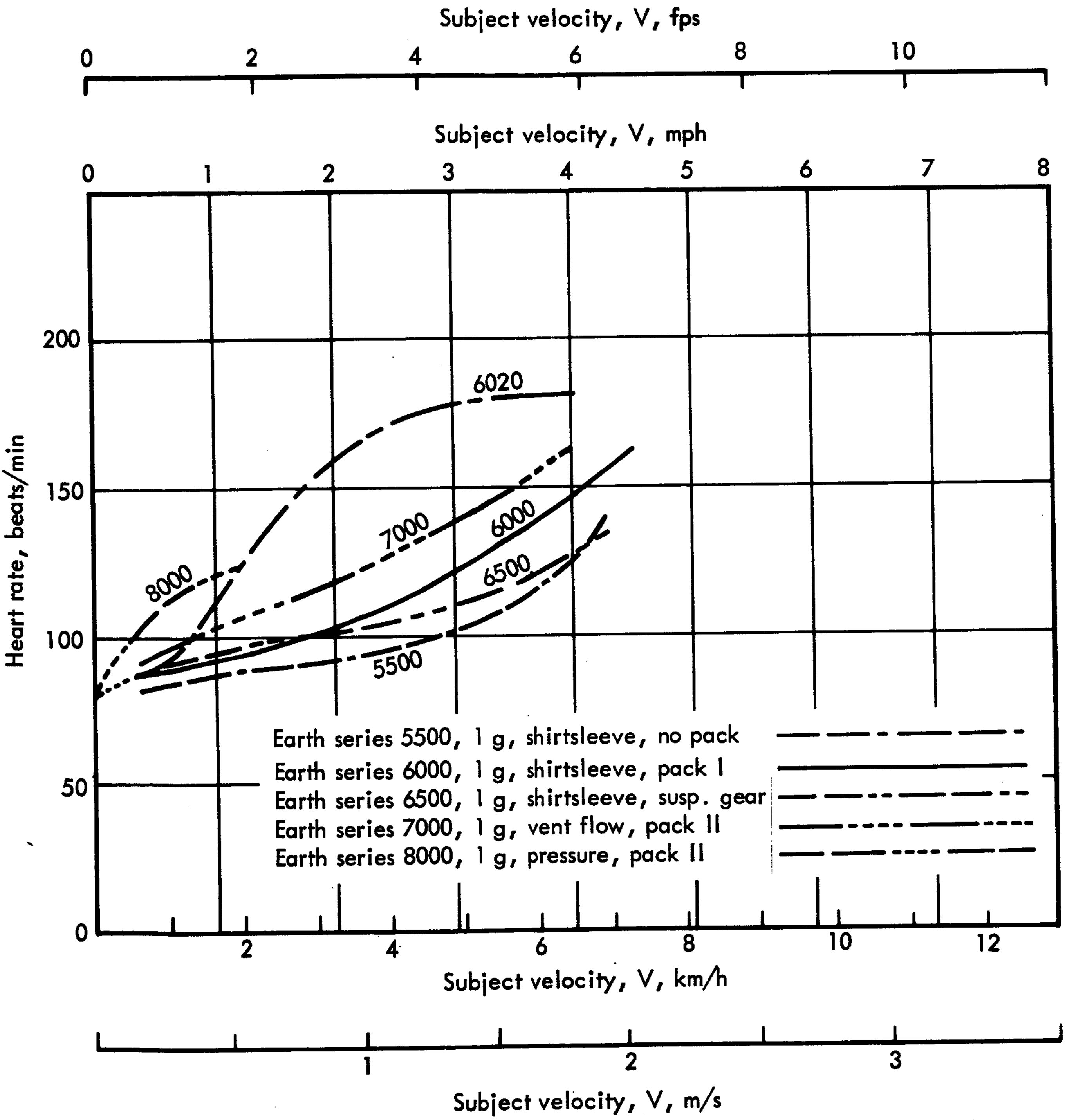


Figure 269. - Heart rate summary for walking and running in 1g tests (series noted)

When the data on mean body temperature was first graphed, location of satisfactory trend lines for body temperature as a function of the subjects' activity level (expressed as subject velocity) proved difficult in some cases. Paradoxical trends were sometimes seen, especially in cases where data on a given test series included results from two or three subjects, or separate runs on the same subject in the same series, sometimes required because of fatigue or other reasons.

When the body temperature data graphs were checked against simultaneous graphs of the ambient (globe) temperature, it immediately became evident that ambient temperature was exerting a dominant influence, often overshadowing the changes in body temperature which normally accompany the increase in body heat production at higher energy expenditure levels. It is for this reason that the body temperature graphs in the preceding result section have been accompanied by graphs showing simultaneous ambient temperature readings.

Although environmental temperatures affected the body temperature readings, it does not appear that the latter changed sufficiently to have affected either metabolic rate or heart rate data significantly. Where a single test session continued for a considerable length of time and involved a series of increasing and relatively high rates of energy expenditure as the test progressed, some rise in average body temperature was observed. At most, the rise was of the order of 1°F, and usually less. In the great majority of test sessions, any change was usually only 0.1° or 0.2°F at the most. Occasional slight declines in body temperature were seen, and are believed to be due either to a dropping environmental temperature or to evaporation of perspiration.

Comparison of the temperature data obtained in test sessions which were, respectively, in the lower and higher ranges of environmental temperature (globe temperatures in the 60's vs the high 80's or 90's) showed that the average body temperatures were considerably more influenced by the environmental temperature than by the subject's relative level of energy expenditure, though also by the clothing worn. A test in which the pressure suit was worn usually resulted in a higher body temperature than one in shirtsleeves, for the same range of environmental temperature.

In comparing shirtsleeve tests on one subject, the body temperature was as low as 93.6°F on a day with globe temperature in the low 60's, and as high as 97.2°F on a day with globe temperatures in the 80's. The range of energy expenditure was comparable. Another subject had an average body temperature in some tests as low as 95.5, and as high as 98.3°F in others. In both cases, the environmental temperature appeared clearly to be the dominant factor.

If the environmental temperature happened to rise in the course of a test session in which there was a relatively small change in the level of energy expenditure, body temperature sometimes rose more than if the environment had remained the same and the rate of energy expenditure had increased markedly. On the other hand, in some tests in which energy expenditure progressively increased to a high level, this was sometimes largely offset by a drop in environmental temperature and the net change in body temperature would be slight.

Figure 270 contains a group of curves which illustrate some of the typical situations just discussed. In this figure, mean body temperature has been plotted separately for subjects A and C against the rate of energy expenditure, in several experimental

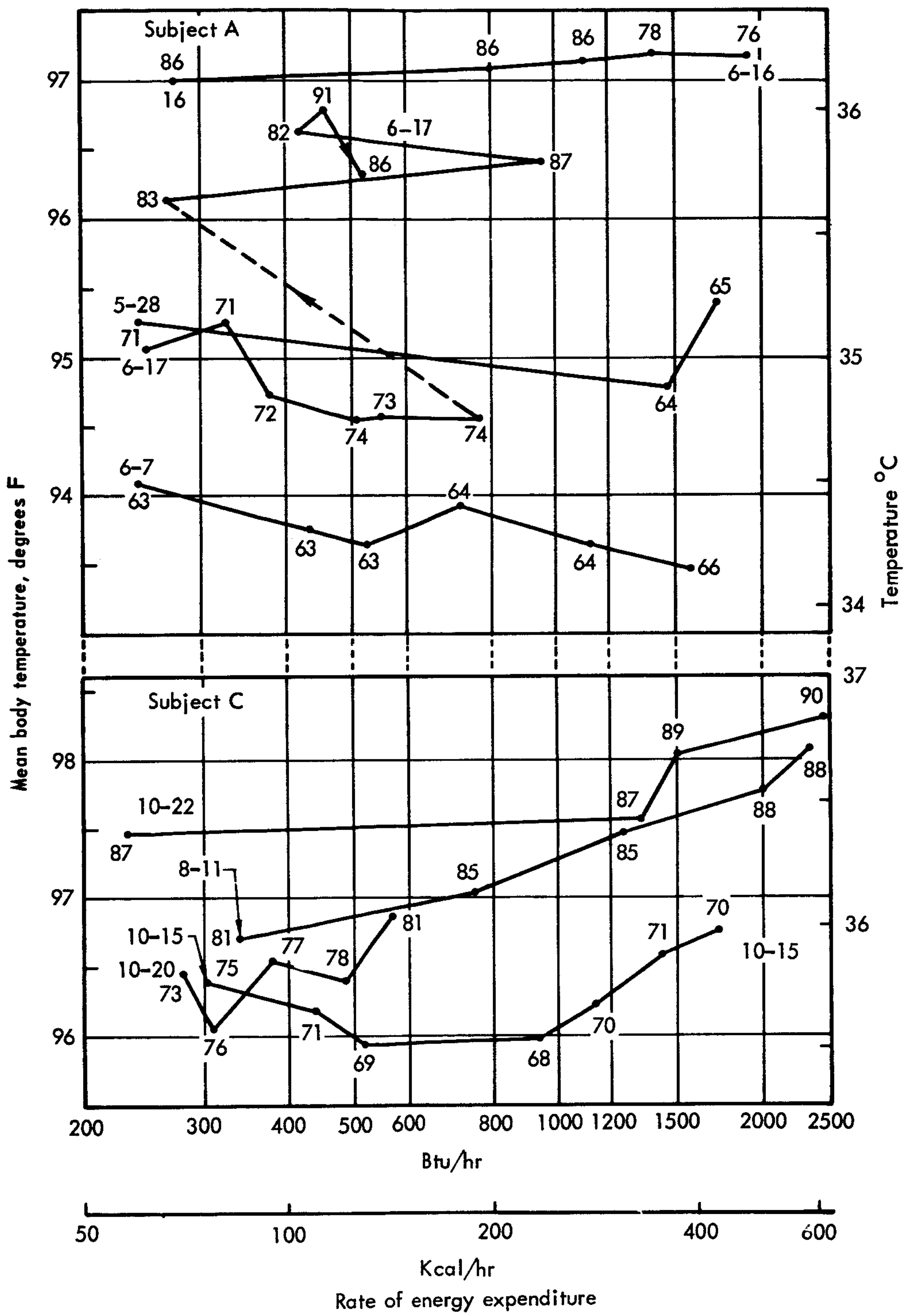


Figure 270. - Course of mean body temperature versus rate of energy expenditure in typical tests. Environmental (globe) temperature noted adjacent to each data point to enable combined evaluation of factors affecting body temperature. Data from subjects A and C presented separately.

runs. Adjacent to each curve is indicated the date of the test run (e.g. 5-28, 6-7, 6-16 etc.), and at each data point is indicated the globe temperature at the time of the body temperature observation.

A detailed description of the various curves will not be given here. However, study of the curves will clearly disclose the separate effects of environmental temperature and metabolic energy expenditure in determining the average body temperature. Note that when environmental temperature was low (in the 70's or lower), mean body temperature tended to decline during a test until the rate of energy expenditure reached about 1000 Btu/hr (250 kcal/hr), or even higher on occasion. On the other hand, when the environmental temperature was in the 80's and above, body temperature tended to rise even at the lower energy expenditure rates, but still more rapidly at the higher metabolic levels.

In view of the body temperature findings discussed above, modification of the temperature measurement procedure is believed to be desirable for future tests in work physiology. Two major considerations are involved: (1) the monitoring points and the weighting schedule used in this program made the resultant average temperature particularly responsive to skin temperature variations, and (2) rectal temperature has considerable lag in its response to changing temperature in tissue masses where heat is generated (particularly the muscles.) It is therefore less valuable as an indication of body core temperature as a whole (as distinguished from skin temperature, which reflects temperature of a thin surface layer only). Although tympanic and esophageal temperatures present practical procedural problems, their use is being favored where it is desired to follow relatively rapid changes in body core temperature, as reflected in blood temperature to which they are principally responsive.

Although the procedure for estimating average body temperature in this program derived from one established by distinguished authorities in the field of metabolic physiology, it is now evident that it is better adapted to the experimental situation in which it was developed than to the dynamic situation comprised in this program. That is, the Hardy-Dubois method is undoubtedly best suited to physiological experiments in a respiration colorimeter, in which air and wall temperatures are substantially the same and change only slowly, and subjects are observed for relatively long periods of time at constant (and generally low) levels of metabolic energy expenditure. Additional analysis of the data from this program should make possible the formulation of body temperature measuring procedures which will provide a more adequate picture of the changing thermal condition of the body as a whole, and its various components, in an experimental program as comprehensive as this.

RECOMMENDATIONS

Although a considerable number of these have already been made throughout the discussion there are several recommendations that are significant and require special attention.

As a result of the experiences gained in the work physiological research of this study the following changes or considerations for future work are recommended and listed on the following page.

Methods

Respiratory hardware. - Since this study included the determination of physical maximum values limited only by a cardiac rate of 180 beats/min, the test subject was exposed to short but very strenuous activities demanding his maximum performance. In the subsequent debriefings the subjects repeatedly emphasized the resistance to breathing and lack of ventilation volume available for inspiration during maximum performance both in the shirt sleeve and pressure suited mode. A small number of tests especially in the pressure suited mode were terminated not by the cardiac rate but by the lack of ventilation volume. The cross sectional diameter of passages in the respiratory hardware for both modes was 0.75 inches. It is consequently recommended that respiratory hardware with a minimum of 1.25 inches diameter be used for human performance testing which reach maximum values. This is in accord with new current recommendations in pulmonary functional testing equipment.

Expired air sampling rate. - Collection of the gas sample from the Mueller-Franz respirometer is controlled by a 0.3% or 0.6% sampling rate. During lower levels of activity and shorter durations these samples were always very small and difficult to analyze correctly. It is recommended that a modification be made to the respirometer to increase the sampling rate control from 0.3% to 2.0%.

Expired air sample. - Collection of gas samples expired under pure oxygen breathing in the aliquot have revealed unstable diffusion problems resulting in a difficult indirect calorimetric analysis. The recommendation is made to investigate aliquot bag materials and to find one that is less permeable to samples expired during pure oxygen breathing.

Procedures

Test duration. - The duration of tests conducted in this study very seldom exceeded 10 minutes. The resulting test data represents the physiological response associated with this finite time period only. It is strongly recommended that similar tests be performed under continuous monitoring to investigate the effects of duration and fatigue upon the physiological parameters of human performance. Only when this is done can complete and confident predictions be made for the assignment of tasks to man on the lunar surface. These assignments can then be made not only for the type of the activity but also its duration.

Additional testing. - Based on the planned lunar surface missions for man the following additional tests are hereby recommended:

(1) unloading and loading of packages and containers to and from different platform heights, the effect of pick-up points, size, shape and weight upon same;

(2) carrying of packages and containers, the effect of pick-up points, size, shape and weight upon same;

(3) pushing, pulling, torquing and hammering at different heights;

(4) effects of different surface features.

Results

<u>Energy consumption of activity</u>. - Further analyses are recommended to determine the energy cost of the activities themselves since the data presented in the results herein includes the energy cost for resting (body maintenance) and thus indicates the absolute energy consumption, rather than the increment due to the work load as such.

APPENDIX A

SUBJECT DATA

By W. Kuehnegger and H. P. Roth

Since one of the primary applications of information derived from this program is estimation of astronaut performance capabilities and limitations under lunar gravity conditions, selection of subjects whose physical and physiological characteristics were reasonably comparable to those of astronaut candidates was considered essential.

GENERAL

Three male subjects were used in the program, two because of availability (especially during the early stages of the program), the third to meet NASA requirements which specified a male subject, age 25 to 31 years; height 5 ft 9 in. to 5 ft 10-3/4 in.; weight 165 ± 10 lb. One of the first two was a research scientist (the principal investigator): age 38; height 67.7 in. (172 cm); weight 186 lb (84.5 kg). The second was a personal equipment specialist: age 32, height 68.5 in. (174 cm); weight 185 lb (83.9 kg). The third was a biology student: age 30, height 68.0 in. (173 cm); weight 135 lb. (70.3 kg). Complete data on anthropometric features and percentile man relationships are found in Volume II, Appendix A.

SUBJECT SELECTION

All subjects had to pass an FAA Class II flight physical examination successfully, and in addition were given periodic tests throughout the program for determination of the physical fitness index (PFI). Such a test is important in selection and determination of the suitability of subjects for human performance testing. It was repeated at intervals throughout the program to check possible conditioning of the subjects. It was found that the PFI remained constant; significant changes would have complicated interpretation of test results. The subjects' physical fitness index (PFI) was determined using the Balke treadmill test of optimal work capacity as illustrated in figure A1.

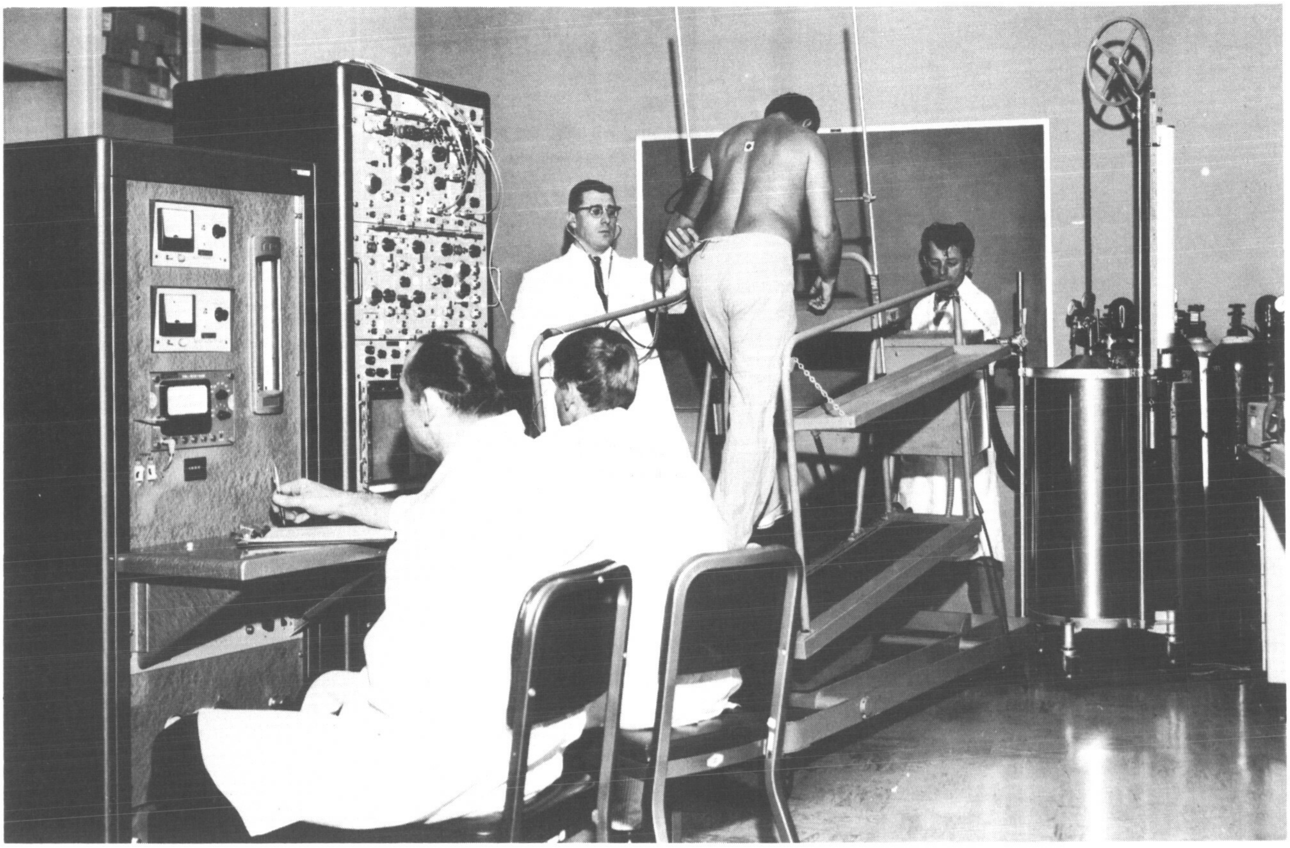


Figure A1. - Test arrangement for PFI determination and physiological base line data

Figure A1 shows a subject on the treadmill; a gasometer is being used to collect exhaled air for determination of his ventilation rate changes during the progressively-increased work levels of the Balke test. The same figure also shows procedure for taking blood pressure during the test. Physiological observations made during the PFI tests provided base-line values for comparison with observations made during the test program proper.

Procedures and calculation of the PFI were as described by Consolazio (ref. 5). The test is performed by having the subject walk on a motor-driven treadmill at 3.4 ± 0.1 mph (90 meters/min). Walking for the first minute is on the level. At the end of the first minute the grade of the walking surface (ratio of vertical rise to distance along the surface) is elevated by two percent. At the end of each succeeding minute, the grade is increased an additional one percent. Walking is continued until the subject's heart rate reaches 180 beats/min. Heart rate and blood pressures are recorded just before the start, during the last half of each minute, and at five minutes after the test ends.

Fitness is estimated by the test duration in minutes prior to reaching heart rate 180. Seventeen minutes is average. Above-average classifications are: good, 18 and 19 min; very good, 20 and 21 min; excellent, 22 and 23 min. A few exceptionally trained individuals may approach 30 min.

The average PFI for the subjects during the test program was computed and is shown in table A1.

TABLE A1. - AVERAGE PFI VALUES

Subject	Duration of Test Min	Balke Rating	Billings et al. Rating
A	15	fair	fair
B	12	very poor	poor
C	18	good	very good

Thus all subjects were in good physical condition. Each was given a basal metabolism test (BMR) during initial evaluation. The resulting metabolic rates were recorded in Table A2 and found to be in the normal range.

TABLE A2. - COMPILATION OF BASAL METABOLIC RATES

Subject	Date	Age	Height/cm.	Weight Kg.	Body Surface Area (m^2)	Normal Calories/Hr. *	Actual Calories/Hr.	BMR in %
A	1/29/65	36	172.1	84.5	1.99	77.3	76.0	-1.8
B	2/1/65	31	173.0	83.9	1.98	77.1	75.0	-2.7
C	7/23/65	30	172.7	70.3	1.82	73.2	79.6	+4.7

* American Journal of Physiology, July 1936

By calculating the B. M. R., which takes into account age, height, and weight, it is possible to compare one person's metabolic rate with that of another. Having obtained a B. M. R. value it is customary to express this value as normal or as a percentage above (+) or below (-) the normal.

The test method used for this investigation was described earlier in this report and is illustrated in figure 3A and 3B.

Pressure Suit Training

Since experiments with subjects wearing pressure suits, both unpressurized and pressurized, were programmed as part of the study, subject indoctrination in pressure suit use was necessary. Subject A had completed this indoctrination almost two years before and was exposed to refresher courses at six-month intervals. Subject B was not used in the pressure suit phase of the program, and hence did not undergo indoctrination. Subject C successfully completed the indoctrination during the training program.

LGS Indoctrination

Subject A was continuously exposed to testing during construction and checkout of the Northrop LGS. For this reason, his learning curve in experience with 1/6 g could not be recorded and evaluated. Subjects B and C underwent identical training on four successive days. Each day's session consisted of six trials each of three maneuvers under 1/6 g, on the LGS, followed by six trials of the same maneuver under one g, to provide baseline values for comparative purposes. The three maneuvers used were the Long Jump, Step and Jump, and Vertical Jump. Performance was scored by the distance (or height) achieved; the average for six attempts was used as the score for each set of trials, Performance ratios for each day's training session were computed, consisting of the ratio of the average performance score at 1/6 g to the average of one g. This permitted more valid inter-individual comparisons because of their anthropometric differences. Figures A2, A3, and A4 show the performance ratios for each maneuver, for the four successive training sessions, each subject being shown by a separate symbol. Improvement in performance under 1/6 g, as training progresses, is evident.

Effects of Training on Physical Performance

It is recognized that repetition of any task will train the subject to perform that task more effectively and with less expenditure of energy. For this reason, it is desirable to precondition test subjects so that their efficiency in performance of tasks used in the experimental program will not vary during the course of the program. This was provided for in the experimental procedures.

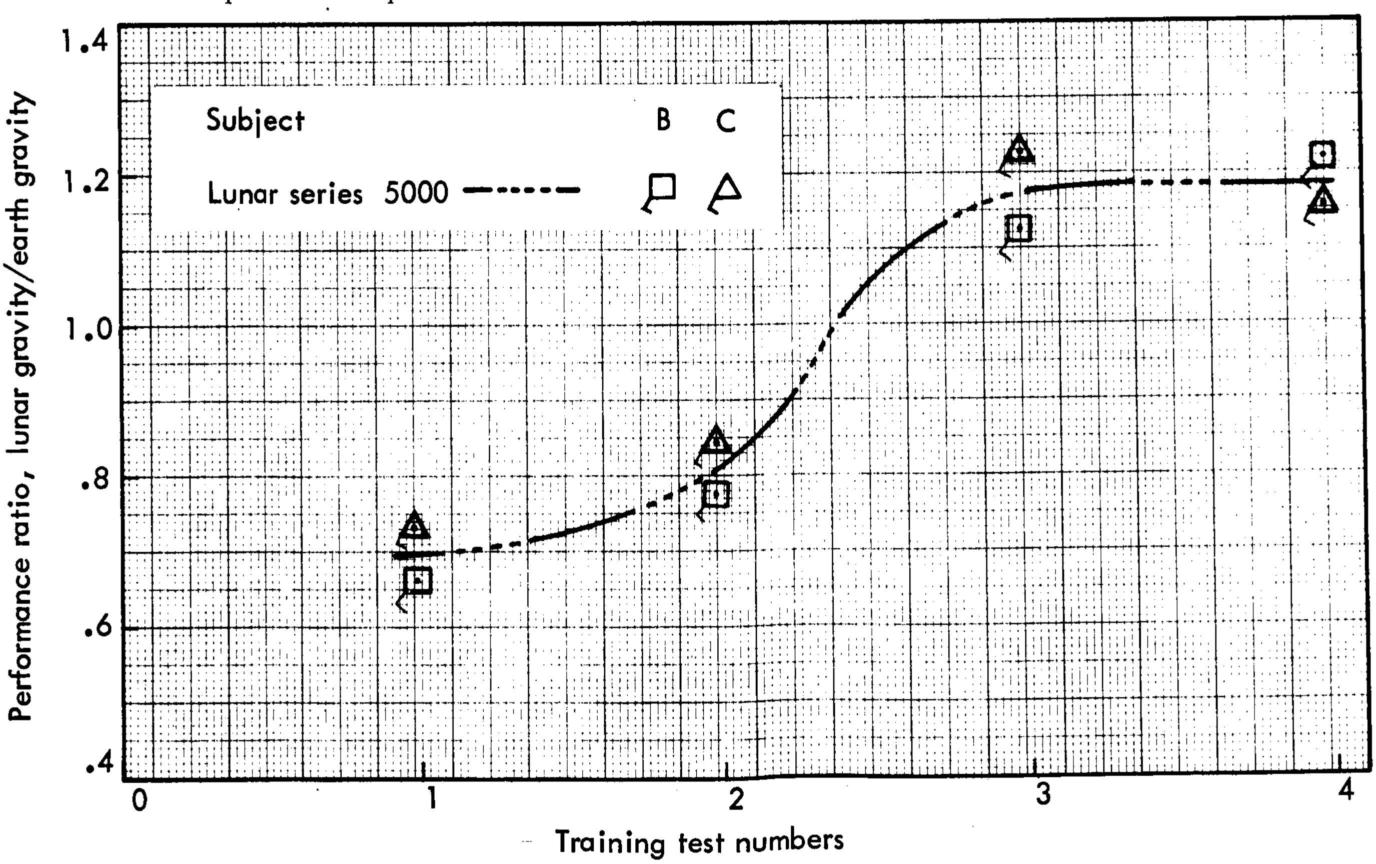


Figure A2. - Average learning curve in long jumps

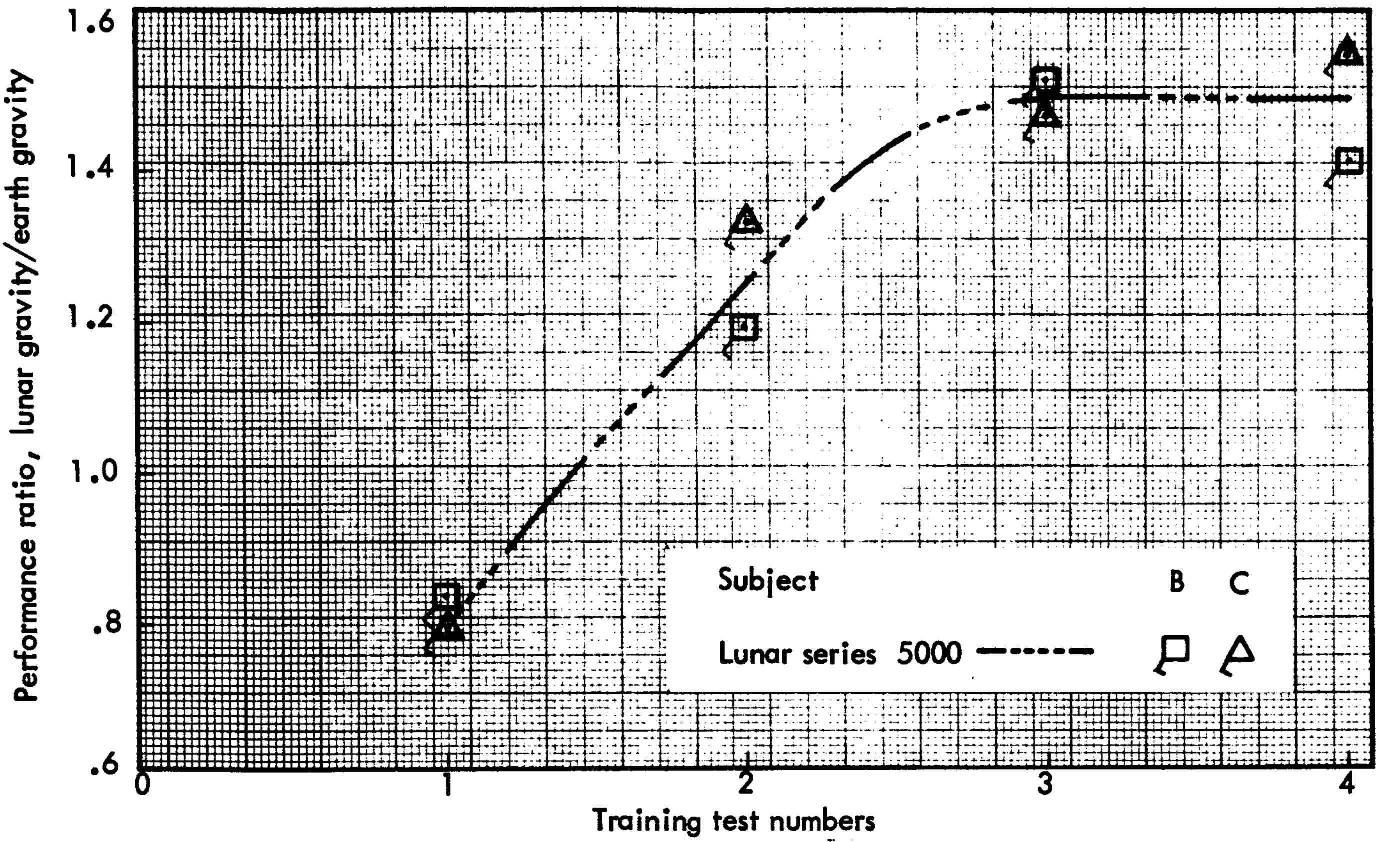


Figure A3. - Average learning curve in step and jump

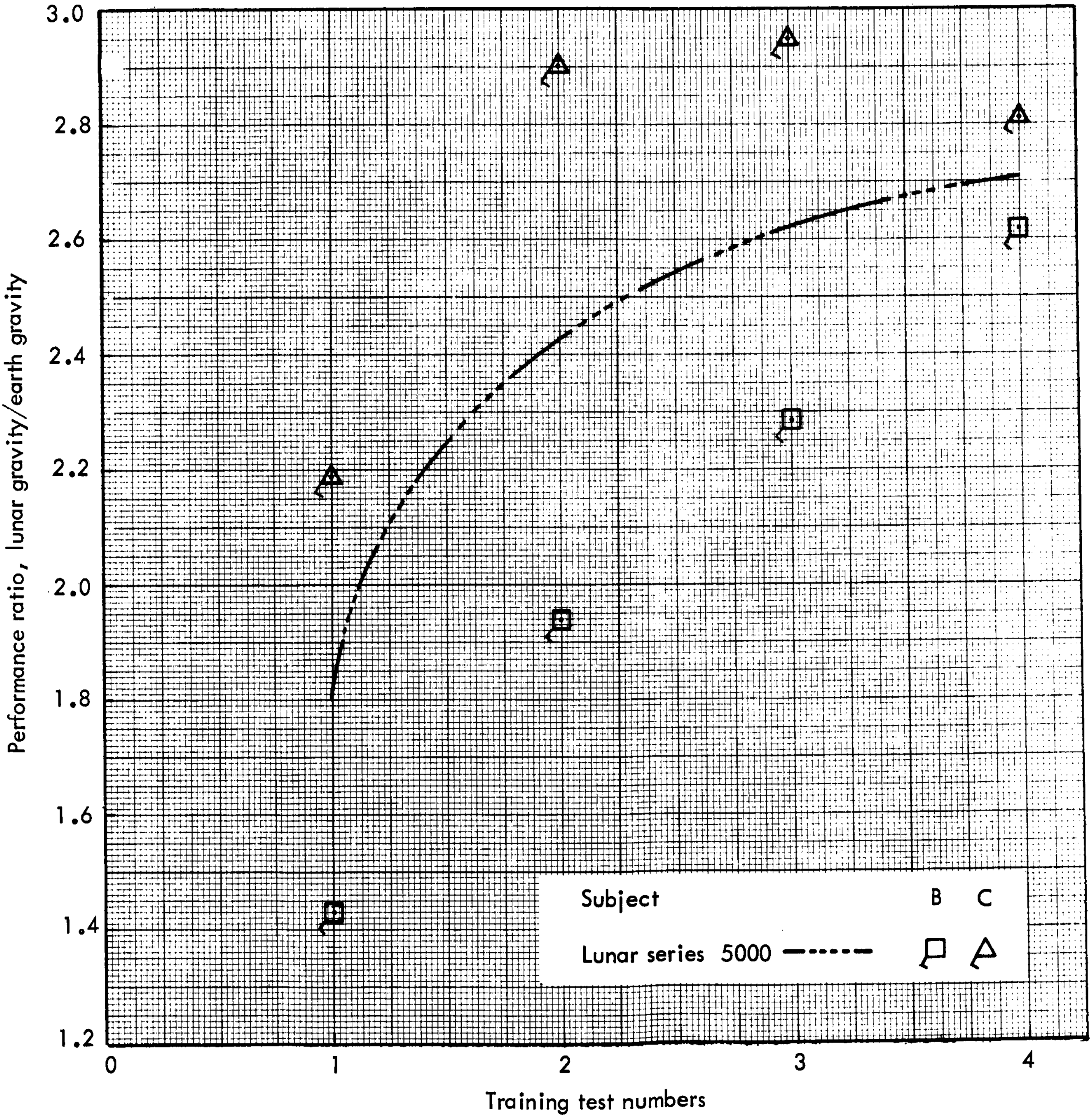


Figure A4. - Average learning curve in vertical jump

APPENDIX B

COMPUTER PROGRAM FOR THE DETERMINATION OF MEAN BODY TEMPERATURE AND METABOLIC ENERGY EXPENDITURE

by

K. L. Forsen

This Appendix describes a computer program to analyze the physiological functions derived from tests conducted under contract NAS 1-4449, "A Study of Man's Physical Capabilities on the Moon." The computer program objectives were to perform necessary calculations required to determine the mean body temperature and metabolic rate of the test subject under simulated lunar gravity conditions, and provide a readout of data in convenient, standardized form.

The Mean Body Temperature and Metabolic Program was based on mathematical information obtained from Reference 20, pages 756 and 762, and Reference 5, page 27. This program embodies two separate subroutine programs that involve the Least Square curve fit method.

Actual data notation is explained in Table B1. The symbols used in the program are explained in Table B2. The derivation of required physiological information translated into mathematical language for computer usage is then discussed. Illustrations of typical elements in the FORTRAN IV computer program layout are also provided. Finally, suggestions for the interpretation of the computer output are offered.

TABLE B1

NOTATION RECORD FOR MEAN BODY TEMPERATURE AND METABOLIC DETERMINATION PROGRAM

A (I)		Field Length
1	Subject letter (A, B, C, etc.)	A1
2	Test number	A4
3	Type of test (Baseline, 1st, 2nd, -- test)	A1
4	Month	I2
5	Day	I2
6	Year	I2
7	Hour	I2
8	Minute	I2
9	AM or PM	A2
10	Globe Temperature ($^{\circ}$F)	F7.0
11	Barometric Pressure, (in. Hg.)	F7.0

TABLE B1

NOTATION RECORD FOR MEAN BODY TEMPERATURE AND METABOLIC DETERMINATION PROBLEM (Continued)

			Field Length
B	(I)	NOTE: Temperatures are given in °F and then converted to °C	
	1	Right hand temperature	F6.0
	2	Right upper arm temperature	F6.0
	3	Left forearm temperature	F6.0
	4	Forehead temperature	F6.0
	5	Abdomen temperature	F6.0
	6	Mid back temperature	F6.0
	7	Mid sternum temperature	F6.0
	8	Left thigh temperature	F6.0
	9	Right calf temperature	F6.0
	10	Left foot temperature	F6.0
	11	Rectal probe temperature	F6.0
	12	Height (inches)	F6.0
C	(I)		
	1	Weight, (lbs.)	F7.2
	2	(M-F) volume reading, (liters)	F7.2
	3	(M-F) temperature, (°F)	F7.2
	4	Barometric pressure, (in. Hg.)	F7.3
	5	(M-F) Correction factor	F6.2
	6	Time, (minutes)	F5.1
	7	FEO_2, reading	F6.5
	8	$FECO_2$, reading	F6.5

TABLE B2

COMPUTER NOTATION SYMBOLS

CA	Total body temperature, (°F)
CB	1/3 total body temperature, (°F)

TABLE B2

COMPUTER NOTATION SYMBOLS (Continued)

CC	2/3 rectal probe temperature, ($^{\circ}$F)
CD	Mean body temperature, ($^{\circ}$F), (CB + CC)
CE	Subject weight, (kg) (not to be confused with caloric Equivalent Figure B2)
CF	Subject height, (cm)
CG	Surface area, (m^2)
DA	(M-F) temperature, ($^{\circ}$C)
DB	H_2O vapor pressure equation, per temperature, ($^{\circ}$C)
DC	Barometric pressure converted to mm of Hg
Test	Test for pressure suit mode. If pressure suit is used DC = 941. 941 mm of Hg at 3.5 psia.
DD	Bar. Pres. - H_2O vapor pressure, (DC-DB)
CH	Reduction to 0°C and 760 mm of Hg and dry of 1 liter of air saturated with humidity
CI	(M-F) volume x correction factor/test duration, (min.)
CJ	Volume expired in liters/min @ STPD, (CI x CH)
CK	1 - (FEO_2 + $FECO_2$), 1-(C(7) + C(8))
CL	Vol. O_2 in cc/min, ((CJ x CK x .265) - C(7)) 1000, .265 is a constant factor of 0_2, N_2 relation between expired air/inspired air.
PK	Correction factor for the use of 100% O_2.
Test	Test for pressure suit mode. During pressure suit mode, CL = CJ x PK (1-C(7) x 1000).
CM	Vol. CO_2 (cc/min) CJ (C(8) - .0003) 1000
Test	Test for pressure suit mode. If applicable, CM = CJ x C(8) x 1000.
CN	Respiratory exchange ratio (RER) vol. CO_2/vol. O_2, CM/CL
CO	Curve fit of RER vs. kcal/liter of O_2, chart
Test	Test for exchange ratio greater than 1.0, IF (CN. GE. 1.0)
Test	Test for exchange ratio less than .707, IF (CN. LE. . 707).
CP	kcal/hr, (CL x CO x 60) / CG x 1000
CR	Standard Man, BTU/hr., (MR), (.369 x 19.37 x CP), Conversion from kcal to BTU x surface area, m^2 to ft^2
CS	10.76 x surface area, (10.76 x CG), Conversion from m^2 to ft^2
CT	BTU/hr, (MR), (.369 x CS x CP)

DERIVATION OF REQUIRED EQUATIONS FOR METABOLIC EVALUATION

I. Surface Area: program symbol CG

W = weight (kg)

H = height (cm)

S = surface area (m^2)

$S = W^{.425} \times H^{.725} \times 7.184 \times 10^{-3}$ (ref 5).

II. Reduction to 0°C and 760 mm Hg and dry of 1 liter of air saturated with humidity. Program symbol CH

A. Obtain water vapor pressure value per temperature in °C (see Figure B1). Program symbol DB (ref. 21).

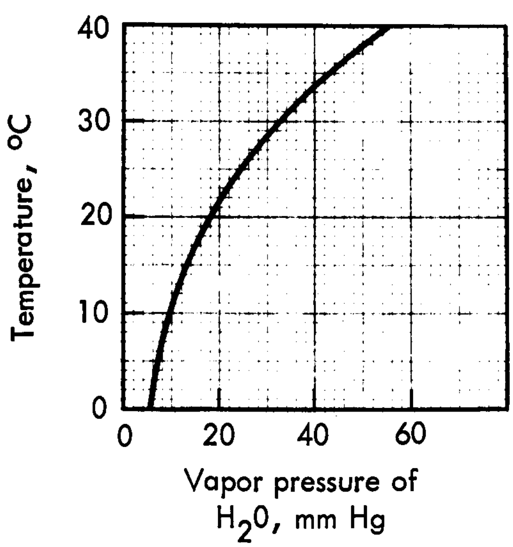


Figure B1. - Vapor pressure versus temperature

B. Subtract: the Vapor Pressure value (DB) from the barometric reading for a given day calculated to mm of Hg (DC). Reference computer program (DD = DC-DB)

C. To obtain standard temperature and pressure, multiply the corrected Hg reading ((DD)/760 mm Hg) by the corrected absolute temperature.

Example: Barometric pressure = 751.5 mm Hg

M-F temperature = 20°C

Computer program symbol = CH

751.5 mm Hg - 17.5 mm Hg = 734 mm Hg = DD

$$CH = \frac{734 \text{ mm Hg}}{760 \text{ mm Hg}} \times \frac{273^{\circ}K}{273^{\circ}K + 20^{\circ}C} = .89999 \text{ (ref. 20)}$$

II Exchange Ratio vs. caloric equivalent kcal/liter of O_2 (see Figure B2). Program symbol CO. To obtain the required kcal per liter of O_2, find the exchange ratio value (CN) on the exchange ratio scale, then read the corresponding value for the kcal/liter O_2.

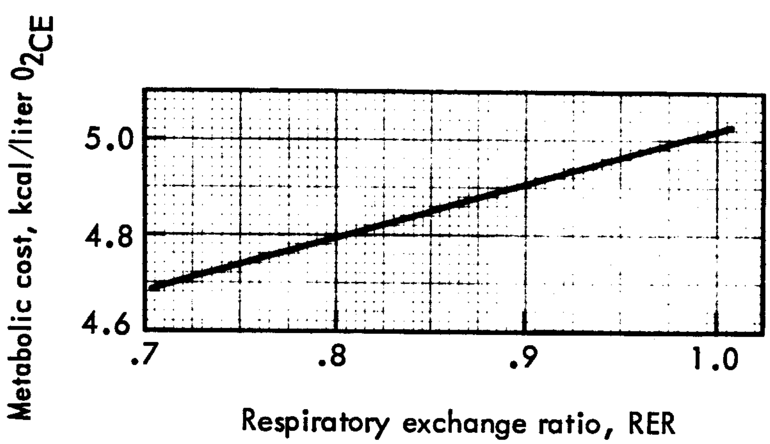


Figure B2. - Respiratory exchange ratio versus metabolic cost

The true value of RER was used within the limits of RER $^{+1.000}_{+0.707}$. When the true ratio exceeded 1.000, the value of 1.000 was used in its place in continuing the computation. When the true value fell below 0.707, the value of 0.707 was used.

COMPUTER PROGRAM LAYOUT

Recording of test data requires a specific punched card format. This format is shown in detail on a typical key punch form (see Figure B3). The arrangement of card sequence for computer processing is illustrated graphically in Figure B4. A diagram showing the flow of operations in the FORTRAN IV program is given in Figure B5, while a print out of the FORTRAN IV program is also included for reference purposes (see Figure B6).

SUGGESTIONS FOR THE INTERPRETATION OF COMPUTER OUTPUT

When there are no body temperatures to be analyzed, recording of the test subject's height is the only data required on card "B". The resulting output for Total Body Temperature, 1/3 Body Temperature, 2/3 Rectal Probe Temperature and Mean Body Temperature will read -0.. If the data cards are incorrectly punched or arranged incorrectly, the computer will either produce an output to read "error source" or will not execute the required data and state the source of error. When any metabolic output reads 0. or -0., the data on cards A, B, or C was incorrectly punched or not given. A sample of the computer output is shown in Figure B7.

KEY PUNCH FORM - GENERAL PURPOSE
FORM 20-708 (R.7-63)

JOB TITLE	ENGINEER	PAGE
Man on the Moon - Mean Body Temperature and Metabolic Determination	K. Forsen	OF

DPWA SERIAL NO.	PRE.	OPD JOB NO.	DASH	FOR ORGN. NO.	ANALYST	DATE
7 0 — 0 0 0 7 0		. . . .	.	NSL-473, Zone 61	Ext. 2894, 2895	

NOTE: All figures are right adjusted. Label all figures from right side of the indicated field.
Index numbers are always 1, 2, 3, as shown.
First set of numbers are all "0".
Next set are all 1, etc. Begin in column #79.
Label only one number or decimal per space.

CARD

A	1	2	3	4	5	6	7	8	9	10	11	- - - - BLANK - - - -			X X X 1
B	1	2	3	4	5	6	7	8	9	10	11	12	Blk		X X X 2
C	1	2	3	4	5	6	7	8	- - - - BLANK - - - -						X X X 3

	A (I)	B (I)	C (I)
1.	SUBJECT LETTER A, B, ETC.	RT. HAND TEMP. (XX.XX), (°F)	WEIGHT (XXX.XX), (LBS.)
2.	TEST No., (XXXX)	RT. UPPER ARM TEMP. (XX.XX), (°F)	M-F VOLUME (XXX.XX), (LITERS)
3.	SEQUENCE TEST NO. (0, 1, 2, 3)	L. FOREARM TEMP. (XX.XX), (°F)	M-F TEMP. OF (XXX.XX), (°F)
4.	MONTH (1, - 12)	FOREHEAD TEMP. (XX.XX), (°F)	BAROMETRIC PRESS. (XX.XXX), (INCHES Hg)
5.	DAY (1, - 31)	ABDOMEN TEMP. (XX.XX), (°F)	CORRECTION FACTOR (XX.XX)
6.	YEAR (64, 65, or 66)	MID BACK TEMP. (XX.XX), (°F)	DURATION (XX.X), (MIN.)
7.	HOUR (9, 10, 11, 12, 1, ETC.)	MID STERNUM TEMP. (XX.XX), (°F)	FEO_2, READING (.XXXX)
8.	MINUTE (1, - 59)	L. THIGH TEMP. (XX.XX), (°F)	$FECO_2$, READING (.XXXX)
9.	AM OR PM	R. CALF TEMP. (XX.XX), (°F)	
10.	GLOBE TEMP. (XX.XX - XXX.XX), (°F)	L. FOOT TEMP. (XX.XX), (°F)	
11.	BAR. PRESSURE (XX.XXX), (INCHES Hg)	RECTAL PROBE (XX.XX), (°F)	
12.		HEIGHT (XX.XX), (INCHES)	

Figure B3. - Typical key punch form

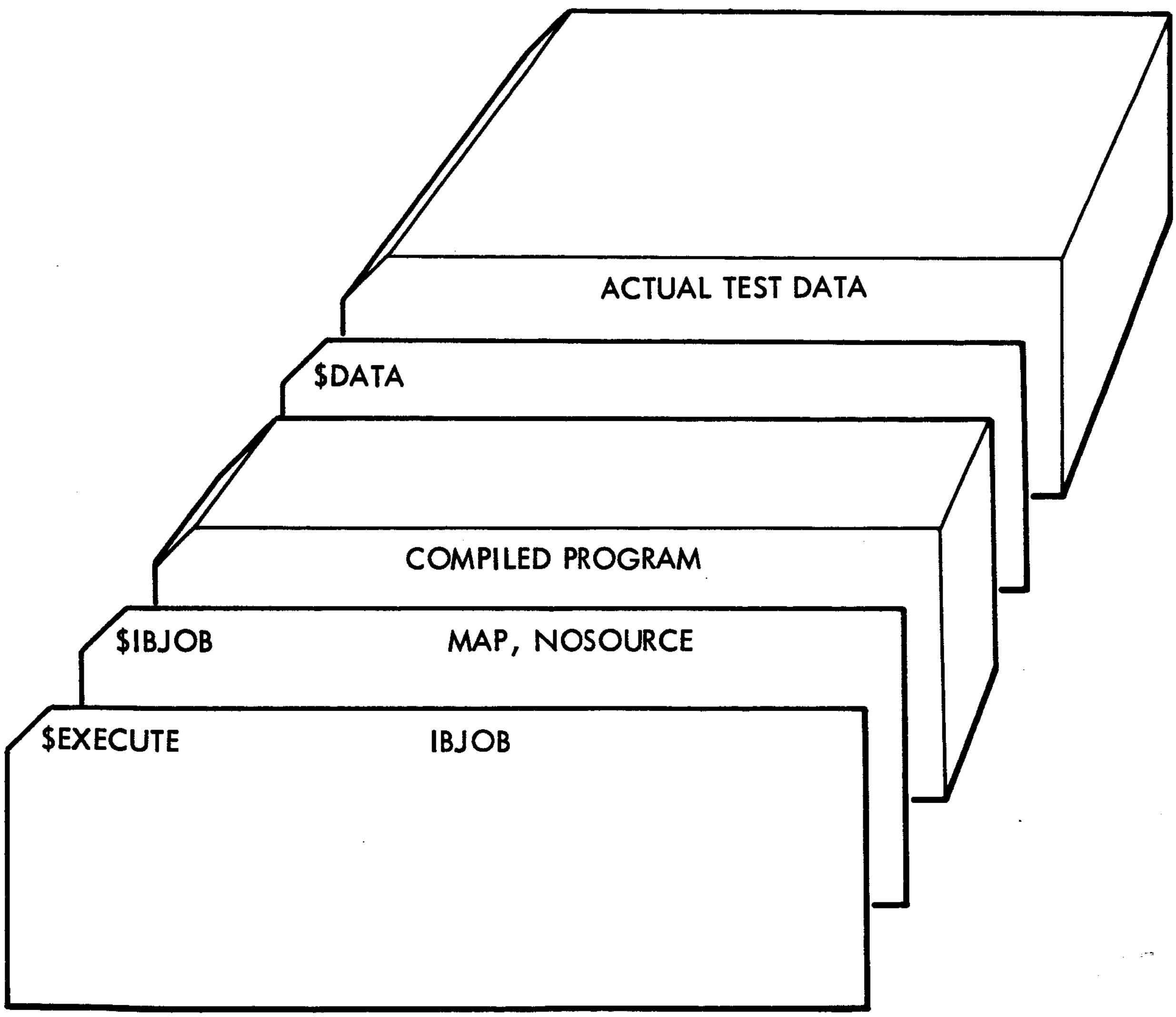


Figure B4. - Arrangement of card sequence for computer processing

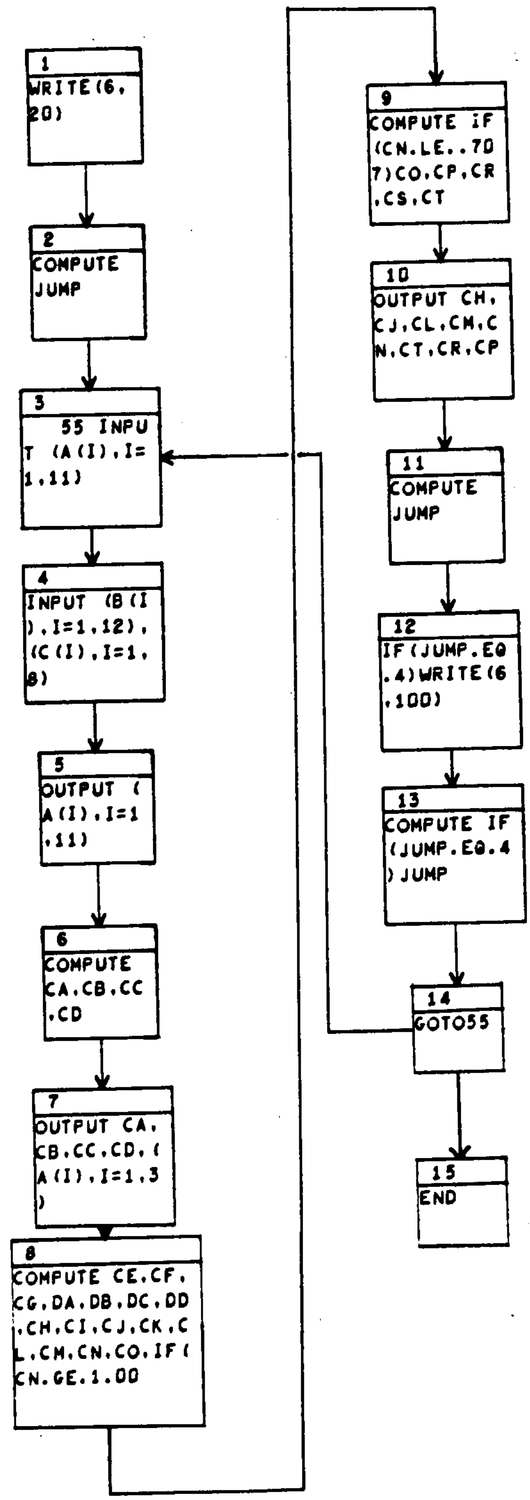


Figure B5. - Fortran IV flow chart

```
      DIMENSION A(50),B(50),C(50)
      DATA T1,T2,T3,T4/4H3000,4H4999,4H8000,4H8999/
      WRITE(6,20)
   20 FORMAT(1H1///////////////14X97HMEAN BODY TEMPERATURE AND METABOLIC
     1DETERMINATION FOR THE MAN ON THE MOON PROJECT, 6-65 K. FORSEN/1H1)
      JUMP=0
   55 READ(5,2)(A(I),I=1,11)
      READ(5,8)(B(I),I=1,12)
      READ(5,3)(C(I),I=1,8 )
    2 FORMAT(1A1,1A4,1A1,5I2,1A2,2F7.0)
    8 FORMAT(12F6.0)
    3 FORMAT(3F7.2,F7.3,F6.2,F5.1,2F6.5,F3.0)
      WRITE(6,25)(A(I),I=1,11)
   25 FORMAT(1H09HTEST NO. 1A1,1H-1A4,1H-1A1,2X5HDATE I2,1H-I2,1H-I2,7H
     1 TIME I2,1H-I2,1H-A2,17H  GLOBE TEMP.(F)=F7.2,13H  BAR. PRES.=F7.3
     2//)
      CA=B(1)*.05+B(2)*.08+B(3)*.06+B(4)*.07+B(5)*.09
     1+B(6)*.17+B(7)*.09+B(8)*.19+B(9)*.13+B(10)*.07
     2+B(11)*.67
      CB=(CA)/3.
      CC=(2.*B(11)*.67)/3.
      CD=(CB+CC)
      WRITE(6,35)CA,CB,CC,CD
   35 FORMAT(1H 28HHEAT TABLE TOTAL BODY TEMP.=F8.3,  17H  1/3 BODY TEMP
     1.=F7.3, 25H  2/3 RECTAL PROB. TEMP.=F7.3/
     21H 16HMEAN BODY TEMP.=F8.3)
      WRITE(6,40)(A(I),I=1,3)
   40 FORMAT(1H037HMETABOLIC DETERMINATION PER TEST NO. 1A1,1H-1A4,1H-1A
     11)
      CE=(C(1)*.45359)
      CF=(B(12)*2.54)
      CG=((CE**.425)*(CF**.725)*.007184)
      DA=.556*(C(3)-32.)
      DB=4.5881+(.3275*DA)+(.01177*(DA**2.))+(.00012865*(DA**3.))+(.0000
     1041*(DA**4.))
      DC=C(4)*2.54*10.
      IF(A(2).GE.T1.AND.A(2).LE.T2.OR.A(2).GE.T3.AND.A(2).LE.T4)DC=941.
      DD=(DC-DB)
      CH=(DD/760.)*(273./(273.+DA))
      CI=(C(2)*C(5))/(C(6))
      CJ=(CI*CH)
      CK=1.-(C(7)+C(8))
      CL=CJ*((CK*.265)-C(7))*1000.
      PK=1.
      IF(DC.EQ.941.)CL=CJ*PK*(1.-C(7))*1000.
      CM=CJ*(C(8)-.0003)*1000.
      IF(DC.EQ.941.)CM=CJ*C(8)*1000.
      CN=(CM)/(CL)
      CO=3.81534+(1.23159*CN)
      IF(CN.GE.1.00)CO=5.047
      IF(CN.LE..707)CO=4.686
      CP=(CL*CO*60.)/(CG*1000.)
```

Figure B6. – Fortran IV program computer listing

```
      CR=(.369*19.37*CP)
      CS=(10.76*C6)
      CT=(.369*CS*CP)
      WRITE(6,45)CH,CJ,CL,CM,CN,CT,CR,CP
   45 FORMAT(1H 12HMHG. FACTOR= F8.4, 16H  VE. LITERS/MIN.=F9.3, 21H  VOL
     1. OF O2 CC/MIN.=F9.3, 22H  VOL. OF CO2 CC/MIN.=F9.3/
     21H 21HRESP. EXCHANGE RATIO=F7.3, 14H  MR. BTU/HR.=F9.3, 19H  STD.
     3MAN BTU/HR.=F9.3,23H  TOTAL K.CAL./M*M/HR.=F8.3///)
      JUMP=JUMP+1
      IF(JUMP.EQ.4)  WRITE(6,100)
  100 FORMAT(/1H1)
      IF(JUMP.EQ.4)  JUMP=0
      GO TO 55
      END
```

Figure B6. - Fortran IV program computer listing (continued)

```
TEST NO. A-1041-1  DATE  6-16-65  TIME  3-15-PM  GLOBE TEMP.(F)=  86.00  BAR. PRES.= 29.860

HEAT TABLE TOTAL BODY TEMP.= 158.735  1/3 BODY TEMP.= 52.912  2/3 RECTAL PROB. TEMP.= 44.220
MEAN BODY TEMP.=  97.132

METABOLIC DETERMINATION PER TEST NO. A-1041-1
HG. FACTOR=   0.8868  VE. LITERS/MIN.=   28.348  VOL. OF O2 CC/MIN.= 1011.667  VOL. OF CO2 CC/MIN.= 1111.239
RESP. EXCHANGE RATIO=  1.098  MR. BTU/HR.= 1216.356  STD. MAN BTU/HR.= 1103.430  TOTAL K.CAL./M*M/HR.= 154.379


TEST NO. A-1042-1  DATE  6-16-65  TIME  3-25-PM  GLOBE TEMP.(F)=  78.50  BAR. PRES.= 29.860

HEAT TABLE TOTAL BODY TEMP.= 158.950  1/3 BODY TEMP.= 52.983  2/3 RECTAL PROB. TEMP.= 44.220
MEAN BODY TEMP.=  97.203

METABOLIC DETERMINATION PER TEST NO. A-1042-1
HG. FACTOR=   0.8661  VE. LITERS/MIN.=   36.381  VOL. OF O2 CC/MIN.= 1275.349  VOL. OF CO2 CC/MIN.= 1426.150
RESP. EXCHANGE RATIO=  1.118  MR. BTU/HR.= 1533.389  STD. MAN BTU/HR.= 1391.029  TOTAL K.CAL./M*M/HR.= 194.617


TEST NO. A-1043-1  DATE  6-16-65  TIME  3-40-PM  GLOBE TEMP.(F)=  76.00  BAR. PRES.= 29.860

HEAT TABLE TOTAL BODY TEMP.= 158.230  1/3 BODY TEMP.= 52.743  2/3 RECTAL PROB. TEMP.= 44.443
MEAN BODY TEMP.=  97.187

METABOLIC DETERMINATION PER TEST NO. A-1043-1
HG. FACTOR=   0.8907  VE. LITERS/MIN.=   55.358  VOL. OF O2 CC/MIN.= 1758.163  VOL. OF CO2 CC/MIN.= 2197.704
RESP. EXCHANGE RATIO=  1.250  MR. BTU/HR.= 2113.890  STD. MAN BTU/HR.= 1917.636  TOTAL K.CAL./M*M/HR.= 268.294


TEST NO. A-1050-0  DATE  6-17-65  TIME 10-15-AM  GLOBE TEMP.(F)=  71.00  BAR. PRES.= 29.980

HEAT TABLE TOTAL BODY TEMP.= 152.520  1/3 BODY TEMP.= 50.840  2/3 RECTAL PROB. TEMP.= 44.220
MEAN BODY TEMP.=  95.060

METABOLIC DETERMINATION PER TEST NO. A-1050-0
HG. FACTOR=   0.9095  VE. LITERS/MIN.=    6.692  VOL. OF O2 CC/MIN.=  239.628  VOL. OF CO2 CC/MIN.=  195.410
RESP. EXCHANGE RATIO=  0.815  MR. BTU/HR.=  275.135  STD. MAN BTU/HR.=  250.016  TOTAL K.CAL./M*M/HR.=  34.979
```

Figure B7. - Typical body temperature and metabolic printout

REFERENCES

1. Wortz, E. C. et al: Body heat storage in full pressure suits. Paper presented at Symposium on Physiological and Performance Determinants of Manned Space Systems Design (sponsored by A.A.S.) April 1965.
2. Lang, R.: Experimental evaluation of ventilation effectiveness of International Latex MK-2 full pressure suit for Apollo space suit program. Report SVI + SER-2599 Hamilton Standard Div. of United Aircraft, April 15, 1963.
3. Wortz, E. C. et al: Full pressure suit heat balance studies. AiResearch Mfg. Co. Report LS-140, Feb. 1965 (Contract NAS9-2886).
4. Roth, H.P. and D.J. Dugas: Thermal balance: a basic problem in space suit design; The RAND Corp. (Internal report) Sept. 2, 1965.
5. Consolazio, C. F., et al: Physiological Measurements of Metabolic Functions in Man. McGraw-Hill Book Co., Inc., 1963, pp 371-374.
6. Freiman, A.H., et al: The electrocardiogram during exercise. J. Cardiol. 20: 506-515, April 1960.
7. Hardy, J.D. and E. F. DuBois: The technique of measuring radiation and convection. J. Nutrition 15: 461-475, May 1938.
8. Blockley, W. V., J.W. McCutchan and C.L. Taylor: Prediction of human tolerance for heat in aircraft; a design guide. WADC-TR 53-346, May 1954.
9. Rossier, P.H. et al: Repiration: Physiologic Principles and their Clinical Applications, (transl. by Luchsinger, D.C. and K.M. Moser), C.V. Mosby Co., 1960, p. 186 et seq.
10. Richards, D.W. Jr.: Respiratory system: external respiration, in Medical Physics. V. 2, O. Glasser, ed., Yearbook Publishers, 1950, p. 836.
11. Haggard, H.W. and L.A. Greenburg: Diet and Physical Efficiency, Yale University Press, 1935, pp. 62,63,68.
12. Issekutz, B., Jr. and K. Rodahl: Respiratory quotient during exercise. J. Appl. Physiol. 16: 606-610, 1961.
13. Poulsen, E., and E. Asmussen: Energy requirements of practical jobs from pulse increase and ergometer test. Ergonomics 5: 33-36, 1962.
14. Margaria, R. et al: Indirect determination of maximal O_2 consumption in man. J. Appl. Physiol. 2: 1070-1073, 1965.
15. Berggren, G. and E.H. Christensen: Heart rate and body temperature as indices of metabolic rate during work. Intern. Z. Angew. Physiol. 14: 255-260, 1950.
16. Brouha, L.: Physiology in Industry, Pergamon Press, 1960, p. 8.
17. Brouha, L.: Discrepancy between heart rate and oxygen consumption during work in the warmth. J. Appl. Physiol. 18: 1095-1098, 1963.
18. Maxfield, M.E. and L. Brouha: Validity of heart rate as an indicator of cardiac strain. J. Appl. Physiol. 18: 1099-1104, 1963.
19. Ralston, H.J.: Comparison of Energy Expenditure During Treadmill Walking and Floor Walking, Jr. of Appl. Physiology Vol. 15, Nov. 1960
20. Best, C. H., and N. B. Taylor: The Physiological Basis of Medical Practice, 7th Edition, the Williams & Wilkins Company, 1961.
21. Hodgman, C. D.: Handbook of Chemistry and Physics, 35th Edition, Chemical Rubber Company, 1953 - 1954.